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Measurement of Spinal Rotation in Gait

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Table of Contents

Table of Figures

List of Tables

Authorship page

Abstract	- Ananya
Executive Summary	- Rohit
Introduction	
a) Literature Review History	- Rohit
b) Uses	- Rohit
c) Medical Conditions requiring Gait Analysis	- Rohit
d) Clinical Gait Analysis	- Rohit
e) Physiology of Gait (Muscle Activity)	- Ananya
f) Spinal Rotation during Gait	- Rohit
Present Studies	- Rohit
Study in Italy	- Ananya
Feldenkrais Core Integration Method	- Ananya
Objectives	- Ananya
a) Initial Client Statement	- Rohit
b) Spinal Rotation during Gait	- Rohit
c) Revised Problem Statement	- Rohit
XI. Methods and Procedures	
a) Difference in Gait when walking on a Treadmill and Ground	- Rohit
b) Discussion of Alternative Designs	- Ananya
i) Measuring Spinal Rotation Using an Optical Mouse Sensor	- Ananya
ii) Calculation of Spinal Rotation Using Precision Potentiometers	- Ananya
iii) String Pot Method	- Ananya
c) Evaluation of Design Alternatives	- Ananya
d) Final Design Choice	- Ananya
a) Detailed Presentation of Final Design	- Ananya
b) Proof of Concept	- Rohit
c) Study Protocol	- Ananya

XIII. Results and Discussions

a) Consistency of acquired Data - Rohit

b) Difference between men and women - Rohit

c) Analysis of Control group and Experimental group - Ananya

d) Regulation (IRB) - Rohit

e) Ethical Issues - Rohit

XIV. Conclusion - Ananya

XV. Future Recommendations - Rohit

XVI. References - Rohit

XVII. Appendix

a) Specifications - Rohit

i) String Potentiometer

ii) DAQ Assistant

b) Bill of Materials - Rohit

c) User Guide - Rohit

g) Results of all Individual Subjects

Abstract

This project determined the spinal rotation during gait walking and compared an experimental group of subjects trained in the Core Integration method to a control group. The angle of the spine was measured using a potentiometer which calculated the movement of the back at the T12 vertebra in the transverse plane. The average angles of the experimental group were 2.7^0 higher than the control group. Other parameters such as angular velocity, angular acceleration, stride rate and stride length were also compared

Executive Summary

The project involved two parts. The first part involved the design and fabrication of a working prototype which can measure the angle of rotation of the spine in the transverse plane during human gait. For this purpose, various design alternatives were considered. After evaluating the design alternatives using a list of objectives and the project constraints, the team decided to build a device based on simple elementary trigonometry and a high precision string potentiometer.

The set up involved the subject wearing a simple leather belt and a chest belt. These two belts hold the potentiometer which is enclosed in a casing up straight in front of the back. The string is attached to the chest belt. Using the movement of the string during walking, the angle of rotation of the spine was calculated using a LabVIEW Program.

The obtained data were processed through a MATLAB file written by the team members which yields a graphical output of the angle measured, its velocity, acceleration, their max values and how they changed over time. The strides per minute and stride length were also calculated. These measurements were analyzed in various ways such as plotting, regression analysis and statistical tests.

The second part of the project involves the recordings of data of two groups of people. Of these two groups, one is the control group which comprises of 15 students. This group is compared to an experimental group of people trained by Dr. Josef DellaGrotte on how to practice the Feldenkrais Core Integration Method. It is hypothesized that the experimental group will have a statistically supported difference in angle of rotation when compared to the control group.
Analyzing the data recorded by our device, we conclude that our hypothesis was proven right and there is a considerable difference in angle of rotation between the two groups. Also, the experimental group had considerably larger values of angular velocity and angular acceleration and paired t-tests established the statistical difference. A regression analysis indicated the dependence of these two parameters on gait velocity. On the other hand, our study did not find any correlation between stride length and gait velocity. The data recorded was done as per IRB regulations. All the subjects have given their consent to voluntarily participate in this study.

1 Introduction

During human gait there is a definite spinal rotation. Though this aspect of gait has not been researched much and poorly understood, it plays a role in human gait and its efficiency. An axial rotation of the spine is observed during human gait because the spine being a segmented rod with various articulations between these segments. Though little is known about the effects of spinal rotation during gait, earlier studies have proved that the resultant forces (both vertical and rotational) on lumbar discs and facet joints during walking reach 2.5 times the body weight. A study has also proved that in the absence of (restricted) spinal movement results in shorter stride length, slower velocity and higher energy consumption in walking. Not only during gait is the rotation of the spine involved, but also during various daily routine activities we do such as running, turning, lifting and also recreational activities like playing squash and tennis. But the extent to which this rotation plays a role in these activities varies. It is also a known fact that excessive rotation of the spine in the industrial area is cause for 60% of the major back injuries.(Kumar)

This study aims to fabricate a device which measures this spinal rotation during walking gait. A list of objectives and constraints will be made in order for the device to meet all project requirements. After studying the considering various design alternatives, the best design suited for this project will be chosen. Also, this study will establish a relation between a control group and an experimental group comprising of Feldenkrais method practitioners. (Kumar) Of the various things which will be compared between these groups, angle of rotation, velocity of rotation, strides and stride length will be included.

2 Background Research

2.1 History of Gait Analysis

Human gait is several million years old. The human being is the only species which places the heel on the ground before the forefoot. Human walking is optimized in a way that makes it the most economical pattern of locomotion. No other species moves as economical as a human being when energy cost per kg body mass per kilometre is calculated. In the middle of last century the science of locomotion greatly advanced with the use of photography. The next major development in gait analysis was with the advent of cine photography. For many years this was the standard technique for gait analysis. In the early twentieth century the development of force plates and the increase in understanding of kinetics were the major break troughs.(R.) The development of treatment regimes often involving orthopedic surgery, based on gait analysis results advanced a lot in 1980's. Soon cinematography was replaced by video cameras which led to the development of computer based analysis systems for extracting kinematic data from videotapes. Many orthopedic hospitals now use gait labs to design treatments and for follow ups. Analysis of gait function has now become part of podiatric medical practice.(Paul)

Figure 1: Typical parameters measured or observed in Gait analysis

2.2 Uses of Gait Analysis

Gait analysis helps doctors identify the causes for walking abnormalities in patients with cerebral palsy, stroke and other neuromuscular problems. The results of gait analysis have been shown to be helpful in determining the appropriate treatment for these patients. In addition to this gait analysis also helps identify the causes for many walking disorders. Gait analysis is an excellent tool for demonstrating changes after treatment or from disease progression.(Simon) For example, gait analysis for a person with Parkinson's disease is an efficient method to test the treatment efficacy of surgical or physical therapeutic interventions. Typically the most common and first method of doing gait analysis is by measuring the cadence of the patient. Cadence includes stride length, velocity and stride width. The typical gait of a person with Parkinson's will have low ground clearance which has a direct effect on stride length and velocity. Similarly for other diseases, gait analysis serves as a function to measure the success of a treatment.

Gait analysis is being used for pre surgical assessment of candidates for high tibial osteotomy, patients with anterior cruciate ligament deficiency and children with cerebral palsy. The joint moments and joint angular velocities which can be determined by gait analysis are used to calculate joint power which summarizes a vital role of muscles during movement such as the muscle’s function as it shortens or lengthens under tension.(Simon)

2.3 Conditions requiring Gait Analysis

Cerebral palsy is a disease that causes physical disability in human development. Gait analysis will aid in finding ways to help the person walk better. More importantly it will help predict which type of muscle, tendon or joint surgery would be most helpful. It also helps evaluate the success of the treatment and enables the doctors to suggest changes in a patient’s exercise program.(national institute of neurological disorders and stroke)

Hemiplegia is a condition where there is paralysis in one vertical half of a patient's body. It is generally caused by a stroke. Leg instability caused by Hemiplegia may make walking unsafe, energy inefficient and painful. The degree of impairment depends on the magnitude of the neurological deficit. In order to compensate for their impairment, they make movements which produce abnormal displacement of center of gravity resulting in increased energy expenditure. (National Institute of Neurological Disorders and Stroke)

Joint diseases such as osteoarthritis of the knee, rheumatoid arthritis, lupus and fractures are very common. All these conditions lead to a change in gait which is energy inefficient and causes pain. Analysis of these problems by dividing them into primary and secondary, deciding an appropriate treatment method to solve the primary problem is possible only through gait analysis.

Prosthetic alignment alters the normal gait as the biomechanics of a prosthetic alignment such as a leg differs from that of a normal leg. Hence studying the differences will help the betterment of physiotherapy for prosthetic gait.(Walter Ellis)

2.4 Clinical Gait Analysis

Typically gait analysis is done using the following instruments.

Video analysis:

Though this is not a very accurate and technical method of doing gait analysis, it does not have any other disadvantages. It will provide a permanent record; it can be viewed repeatedly and can be watched in slow motion. General observations like symmetry, speed, acceleration and fluency can be made. Also the three stages of gait cycle, heel strike, mid stance, and toe off can be analyzed with video analysis.(Green)

Figure 2: Video analysis being done on a person running on a treadmill

Force Plates:

Force Plates are expensive but measure ground forces which are not visible to the eye. These ground reaction forces are externally applied and constantly affect human locomotion. Force Plates can be used for measuring forces of stepping, jumping and other human scale actions. It is also objective, non invasive and very easy to use. The major disadvantage of force plates is their inability to measure successive events during locomotion. Hence for sufficient data acquisition, multiple trials are necessary. The design of the force plates also limits the type of subjects which can be used. From a researcher stand point, not all animals can be tested on a force plate based on their weight and size. (MF)

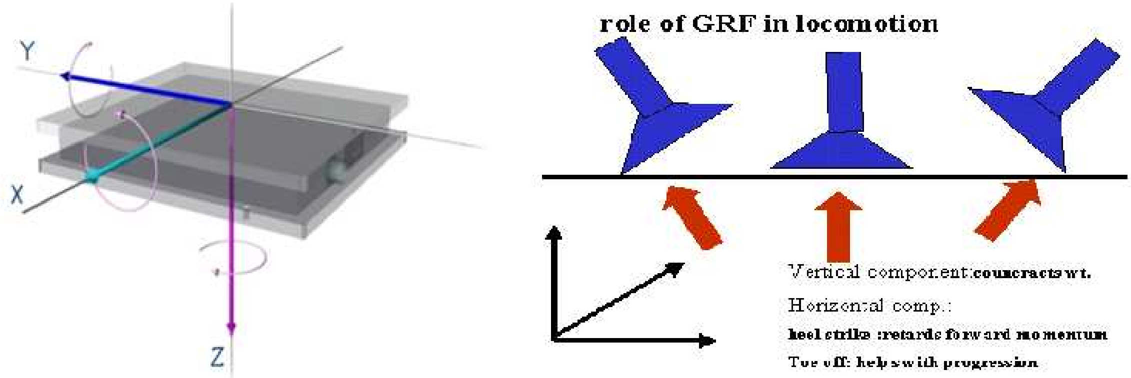


Figure 3: Co-ordinates of force plate measurements

Electrogoniometers:

Electrogoniometers can be used to accurately measure joint movements in multiple planes accurately. They consist of one or more potentiometers or strain gages between two bars. The arms of an electrogoniometer are fixed to a limb with straps such that its center coincides with the center of rotation of the joint. As the angle of the joint changes, the electrical resistance of the potentiometer also changes. Depending on the angle of motion, a varying output voltage is produced by the potentiometer.

They can be single axis or twin axis. Single axis goniometers measure rotation in one plane such as forearm supination or neck axial rotation. Twin axis goniometers can measure angles in two planes of movement. There are two separate output connectors; one measures flexion/extension and the other measures radial/ulnar deviation such as wrist movements. Electrogoniometers can be connected to a display unit and data can be displayed on an LCD. Electrogoniometers are easy to use and process, cost less and are portable. Depending on the attachment, electrogoniometers sometimes do not give data with respect to global reference system. Also there is a difficulty in monitoring joints surrounded by large amounts of soft tissues (hip).(Bronner)

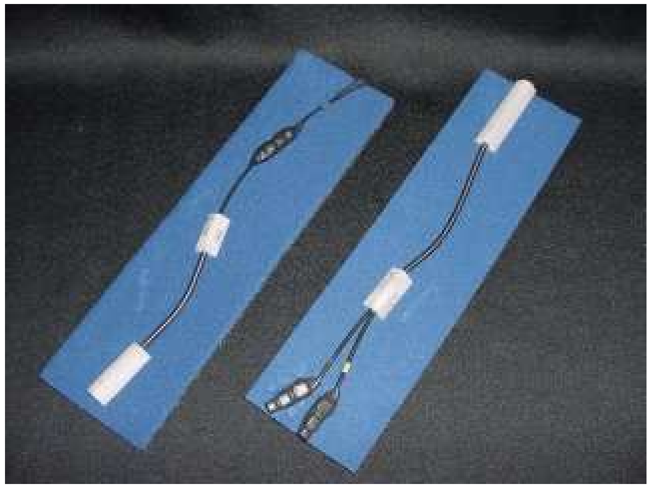


Figure 4: A twin axis electrogoniometer

Accelerometers:

Accelerometers work on the principle of inertia. A single axis accelerometer is made up of a known mass suspended from a strain gage. Motion deflects the strain gage which is translated into an electrical signal. Using piezoresistive devices, triaxial accelerometers have been developed which can measure 3D acceleration. (H. Marko)

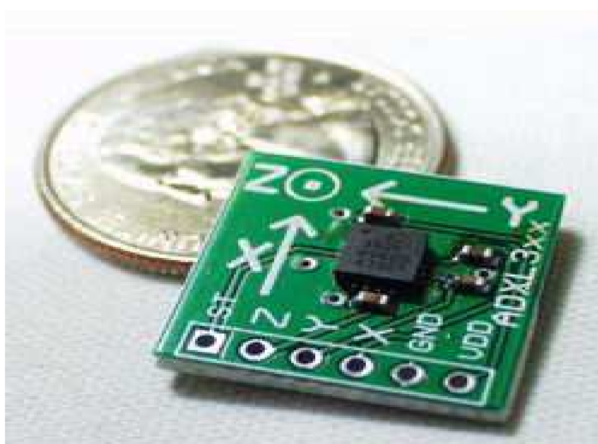


Figure 5: A three axis accelerometer

Accelerometers can be used in measurement of rotational segment motion over a broad frequency range. They are also small in size and inexpensive. Some of the disadvantages include the fact that they cause signal drift creating increasing artifact over time.(H. Marko)

2.5 *Muscle Activity during Gait Cycle*

The movement pattern observed during walking results from the interaction between external forces (joint reaction and ground reaction) and internal forces (produced by muscles and other soft tissue). A full gait cycle is described as the undertaking of both stance and swing phases by one limb. Gait involves the accomplishment of three key functions: weight acceptance, single limb support, limb advancement. Phases of gait cycle are divided into different events. The stance phase takes up 60% of the gait cycle. The five different events in the stance phase are initial contact, loading response, mid stance, terminal stance and pre-swing. The events in swing phase are initial swing, mid-swing, terminal swing. (Gait)

Weight acceptance:

In this phase, an unstable swinging limb is prepared to accept rapid transfer of body weight in a stable platform. This is the first step in preserving the aim of gait which is progression. It has two phases:

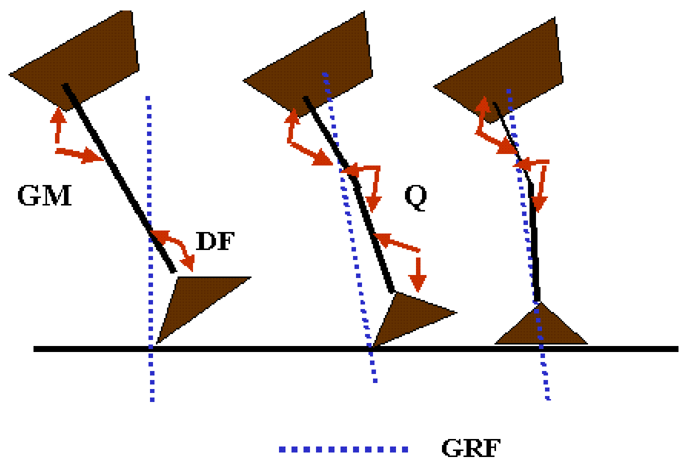


Figure 6: IC to Loading Response

Initial contact

Initial contact is when the foot touches the ground. During initial contact, hip is flexed, knee is extended, ankle is dorsiflexed to neutral and floor contact is made with heel. Ground reaction force is anterior to the joints except for the ankle which is posterior and creates plantar-flexion moment.(Gait)

Loading Response (0 to 12 percent of gait cycle)

Maximum muscle activity occurs during this period. This phase begins with full floor contact and ends with the opposite foot lifted for swing heralding the beginning of single limb support. As the body weight is transferred onto the forward limb, knee is flexed for shock absorption. Knee flexion is brought on by GRF (ground reaction force) vector going behind the joint. This phase also involves a brief period of double limb support.(Gait)

Single limb support:

In this phase the single supporting limb supports body weight in both sagittal and coronal planes, while maintaining progression.

Midstance (12 to 31 percent of gait cycle)

As the body moves over the stance limb, activity in the foot's intrinsic muscles (which are primarily subtalar supinators) activate to convert the foot into an increasingly rigid structure. This event involves the first half of single limb support. The mid stance finishes when body weight is aligned over the forefoot. (Gait)

Terminal Stance (31 to 50 percent of gait cycle)

When continued forward momentum in the body's upper part causes the heel to rise from the floor and the body weight moves ahead of the forefoot. (Gait)

Limb advancement:

The limb is now prepared to advance and forward the limb for progression. There is no GRF (ground reaction forces) in swing phase. Limb progresses due to inertial force and muscle activation is required to control limb advancement.

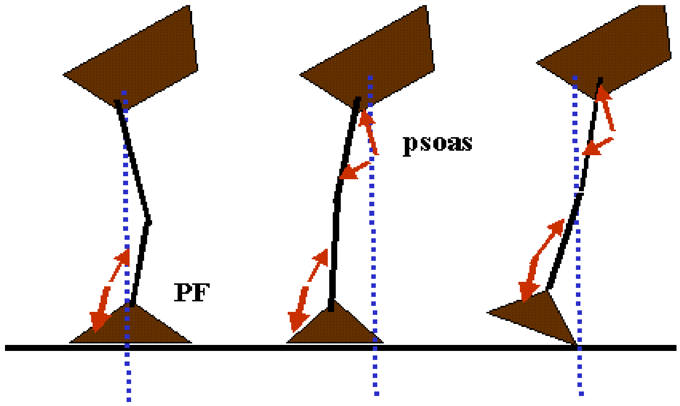


Figure 7: mid-stance to pre-swing

Preswing (50 to 62 percent of gait cycle)

As in the loading response, there is widespread muscle activity in this period. The foot's position is supinated and rigid. In this stage the supporting limb off-loads weight and prepares to swing.(Gait)

Initial Swing

The purpose of this stage is to clear the foot off the floor and advance it. It ends when swinging foot lies opposite the stance foot. This movement is achieved by hip, knee and ankle flexion.

Midswing

In this stage there is minimal muscle activity. The dorsiflexors are carried through the swing like a pendulum due to the extremity's inertia. The foot is advanced and ends when tibia lies vertical.(Gait)

Terminal Swing

The swinging extremity is slowed down by the hamstrings. During this phase leg moves ahead of the thigh and ends when foot strikes the ground.(Gait)

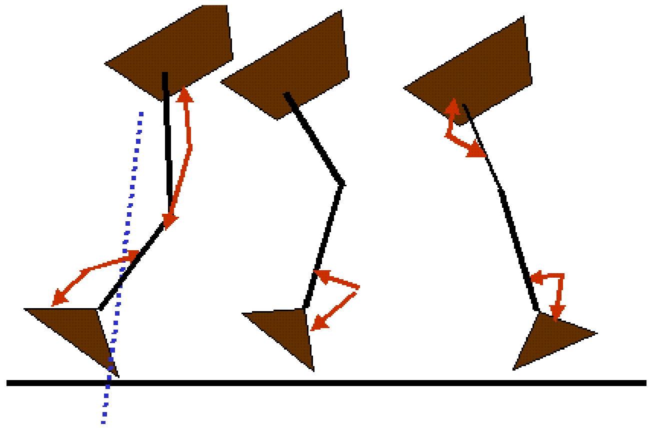


Figure 8: Initial swing to terminal swing

2.6 Differences in gait in treadmill walking and ground walking

Treadmills have been widely used for gait analysis for human and animal studies. Many studies have been done to report how treadmill walking differs from over ground walking. According to some authors there is no clear difference between the two types of walking. However, differences in several aspects of walking have been pointed out by other authors. Most studies and experiments including those of Murray et al., 1985; Stolz et al., 1997; Alton et al., 1998 confirmed that while stance period is decreased in treadmill walking, cadence is increased. T. Warabi et al conducted a study in which statistical comparisons were made for 10 subjects between treadmill and floor walking. Comparing male and females as two separate groups showed no differences. Therefore, the 10 subjects were compared together as a group. (Warabi)

The results of the study showed that stance phase on treadmill walking decreased to 93.2% of the over ground walking. Moreover, the standard deviation of the stance in treadmill walking was much less than that in over ground walking, implying that there is more variation in over ground walking, while treadmill walking is more regular. The same study showed that cadence increased in treadmill walking to 106.6% of floor walking. Thus it was concluded that humans reduced the stance phase by about 7% and increased the cadence by 7% in treadmill walking and ended up walking with the same speed in both the treadmill and the floor.(Warabi)

Strain gage contact times at 5 different points were measured. Strain gage contact times are known to vary with speed. As the speed was the same in both forms of walking, the strain gage contact times of both were compared. The experiment showed that the strain gage contact time at the heel was significantly lower (81.2%) in treadmill walking than floor walking. Additionally, the contact time of the toes on the treadmill were 90.6% - 93.6% of the floor walking. These two factors also contributed to shortening of the stance period.(Warabi)

Thus, T. Warabi et al concluded that the lower limbs are automatically and regularly pulled back on the treadmill. Therefore, afferent impulses affect the locomotor pattern generator resulting in a regular walking pattern. However, in floor walking, walking is influenced by several visual and vestibular external factors which lead to a more variable walking pattern. It can be concluded from this discussion, that although some statistical differences do exist, there is a high grade of similarity between the two modes of walking and for our purpose of analyzing the gait and measuring spinal angles, the effects of these statistical differences would be negligible.(Warabi)

3 Feldenkrais – Core Integration Method

Core Integration is a method of movement education, bodywork, and therapeutic exercise designed to help an individual move better and feel better. It is an awareness-based and body-focused learning process that uses gentle movement explorations to help individuals find more comfortable, stress-free ways of moving and doing daily activities. It is meant to teach an individual to move the way he/ she were designed to move; to have his/ her effort directed along specific core movement pathways without excess tension, restrictions, or faulty habits. The method was developed by Josef DellaGrotte, PhD. It is based on the work of Dr. Moshe Feldenkrais and other body-mind exercise forms. (feldnet)

Core Integration (CI) organizes movement into six primary pathways. These pathways along with strengthening of the body provide the most efficient way of moving. Also they allow the body to lengthen and become more flexible. The most commonly reported benefits include decreased aches and pains, improved posture and a longer, less compressed spine, strain-free core strengthening, improved flexibility, and renewed vitality.(feldnet)

This Method was proposed based on a sophisticated understanding of the way individuals organize potentials for movement and skill, for consciousness and thought, and for making effective relationships with the world we live in. Along with employing what is common to all human beings, it uses the opportunities afforded by individual learning styles. The Method takes its place among the most advanced schools of thought and practice that address the development and enhancement of ability and the capacity for change. It incorporates an understanding of the development and the mechanics of human movement. The ***Feldenkrais Method*** offers an intriguing and powerful way of working with people.

Core Integration consists of 15 Principal Exercises using the six primary pathways which are the meridians of functional movement. In addition CI- awareness is imparted through movement floor lessons based on the principles of Dr. Feldenkrais which teach a self connecting learning process, corresponding with and supporting the exercises. Fitness bands are also used to connect, integrate, and strengthen dynamic walking.(feldnet)

4 Problem Statement

4.1 Initial Problem Statement

The goal of this project is to design and implement a measuring apparatus to track the torsional rotation of the spine for the purpose of gait analysis. The technique adopted should be in vivo, efficient and reliable enough to differentiate the gait parameters of normal gait and that of a person who underwent the educational therapy utilizing the core integration method. In addition to being accurate the apparatus should be within the budget limits of the project. This technique should be safe for the subjects and should satisfy the IRB regulations.

4.2 Revised Problem Statement

The goal of this project is to design and construct a device to measure the spinal rotation of a person during gait. The technique adopted should be in vivo, efficient and reliable. The accuracy of the device should be less than 1^0. To be able to better represent the data the precision of the readings needs to be high. Also, the protocol for the procedure needs to qualify for the expedited IRB approval. The procedure and device components should not pose any threat or pain of any sort to the subjects on whom the device will be used upon. To accommodate people with different heights, the length of the device needs to be adjustable. The device should be able to fit people with different builds. Also, there needs to be included a feature in the device which take the correct baseline by having a predetermined offset. The device should not only be providing the angle of rotation of the spine, but also the number of strides the subject took in a given period of time. The overall setup of the measuring apparatus should be able to calculate variables which can be calculated by measuring the angle of rotation and strides such as strides/minute, angular velocity, angular acceleration and maximum angle of rotation. To represent the data of each subject, the setup should be at least able to give a graphical output of the measured angle of rotation in a specified period of time. The device should be made to resist wear as it would be used to on a number of subjects over a period of time. Also, the device should be capable of being easily modified to be able to be used on both males and females of different builds. The device's setup, if it includes any electronic equipment such as wires or, batteries, and also the overall weight of the device should not cause any inconvenience to the natural gait of the person. Two groups, the control group and the experimental group should be analyzed and compared with each other in various ways. The control group should include people, with no experience or familiarity with race walking or any kind of efficient walking techniques. The experimental group should consist of people who have had training on using the Feldenkrais Core Integration Method. Both the groups should have a reasonable mixture of males and females. For testing the subjects of both the groups, the exact same device and the exact same protocol should be used. The total expenditure in constructing the device should fall within the budget given for the project.

5 Methods and Procedures

5.1 Discussion of Design Alternatives

5.1.1 Measuring spinal rotation using an optical mouse sensor

Keeping our goal of measuring rotation of the spine while walking and thus quantifying gait for the purpose of comparing commonly observed gait to regular gait, several approaches to this task were considered. An approach to this problem was made using an optical mouse sensor. The approach is based on the works of Donatell et al. An optical mouse was first developed by Agilient technologies and introduced in 1999. The optical mouse is able to work on all kinds of surfaces and works by taking thousands of pictures per second by using a tiny camera (Donatell).

Optical mice consist of a small red light emitting diode which emits light on to a surface and light is bounced back on to a complementary metal oxide semi conductor (CMOS). For our experiment, we could use laser based optical mice which work on more surfaces than an LED mouse. Once the CMOS receives the image, it is sent to a digital signal processor (DSP) for being analyzed. Patterns in the image and their movement since the previous image are detected by the DSP. The change in patterns over a sequence of images is analyzed by the DSP and it determines the movement of the mouse and the corresponding coordinates are sent to a computer. The computer records the coordinates and the cursor moves on the screen based on this. This happens very frequently, about a hundred times per second, making the cursor move very smoothly.

We considered employing the same principal of working of an optical mouse by making some modifications. The LED used in an optical mouse is sensitive over a very small range and motion cannot be detected one the mouse is lifted off the surface of the table. In our experiment, the back is used as the surface and will be constantly moving away from the sensor, hence we will employ an LED with a much bigger range such that the mouse is more sensitive (Donatell).
The rest of the setup for the optical mouse sensor would consist of a long metal blade attached to a belt with an optical mouse sensor at the other end as shown in the figure below. The belt is worn at the hip and the optical mouse sensor reaches over the 12^{th} thoracic as this rib is expected to move the most with respect to the hip while walking. Thus the angular rotation of the spine is determined with respect to the hip. The rotation angles of the hip during walking are available from previous research.

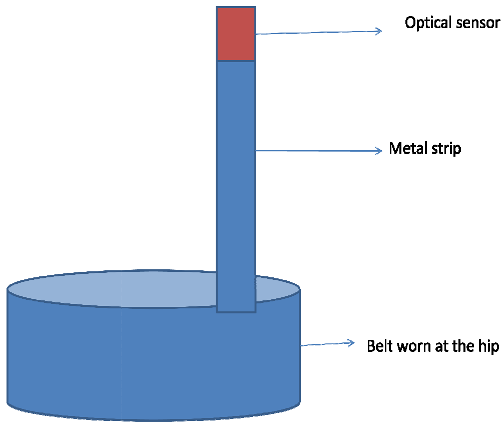


Figure 9: Belt attached to the metal strip and sensor

The optical mouse sensor detects the distance moved by the back in the transverse plane. The movement is measured by analyzing change in the surface pattern over a sequence of images as discussed previously. The sensor sends each image to a digital signal processor. An electrogoniometer is used to calibrate it initially and a neutral position is determined. The distance moved by the back is used to calculate the angle of rotation.

The angle is calculated by using the formula:

Angle = length of arc/ radius.

Where, radius is half the length of the back

Length of arc is the distance moved by the back.

5.1.2 Calculating spinal rotation using precision potentiometers

Another approach to measuring spinal rotation can be made by using precision potentiometers firmly strapped to the pelvic girdle and the shoulders. This approach is based on the works of van Leeuwen et al who came up with a technique to measure pelvic rotation for a subject walking on a treadmill. Our experiment would make use of their methods and results to calculate pelvic rotation and the same technique would be used to calculate the rotation of the shoulders. Thus we will approach the problem of calculating spinal rotation by identifying pelvic rotation and rotation of the shoulders and subtracting the angles. A relation would be determined between the two angular values and would be used to calculate the spinal rotation (Leeuwen). van Leeuwen et al used an external “pelvis girdle” to record pelvic rotations. The girdle is shown in Figure 10.

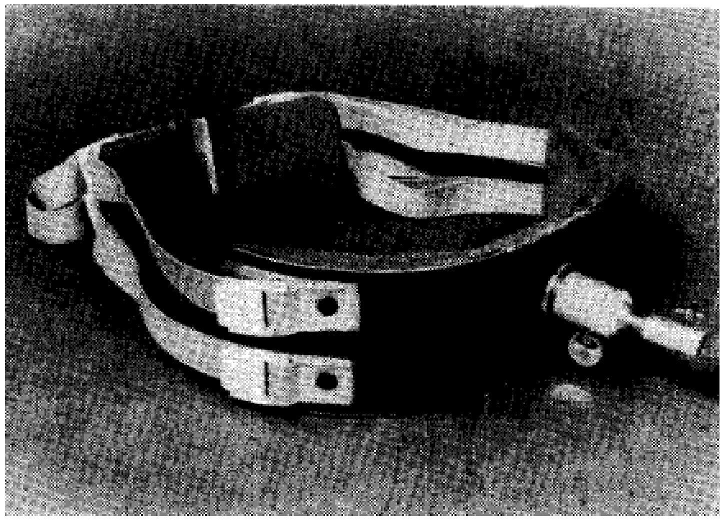


Figure 10: External Pelvis girdle

Van Leeuwen et al estimated the pelvic deviation by treating the mounted girdle as a spring damper system and used the following expression to calculate the angle:

$$J\ddot{\theta} = c_1\theta + c_2\dot{\theta} + M$$

Where, J was the moment of inertia

C_1 was the spring coefficient

C_2 was the damping coefficient

M was the external moment applied to the girdle in the considered direction.

While the moment of inertia was calculated from pendulum experiments, M was calculated using force transducers. The angular acceleration was obtained by using accelerometers and was integrated to find the angular speed and Θ. By making successive recordings c_1 and $c_2$were estimated (Leeuwen).

It was found that the damping influence was negligible compared to the elastic influence and the angle of deviation could be calculated from the following expression:

$$\theta_{max} = (J\ddot{\theta}_{max})/c_1$$

Thus we could use the findings of van Leeuwen et al to calculate the pelvic angles and use a similar technique to find the rotation of the shoulders. However a major drawback is that the external pelvis girdle and the other apparatus used in the experiment is hard to build, leading to inaccuracies. Also, we will need to assume that the spinal rotation can be obtained by combining the values of the pelvic rotation and the rotation of the shoulders.

5.1.3 Measuring Spinal Rotation using a String Potentiometer

Another approach is by using potentiometers to detect the motion of the body and use that to calculate the spinal rotation. This approach was similar in principal to the optical sensor approach as it used trigonometry to translate the transverse motion of the back into spinal rotation. However, it used a potentiometer as a sensor to detect the motion. Figure 11 shows the picture of the finished product.

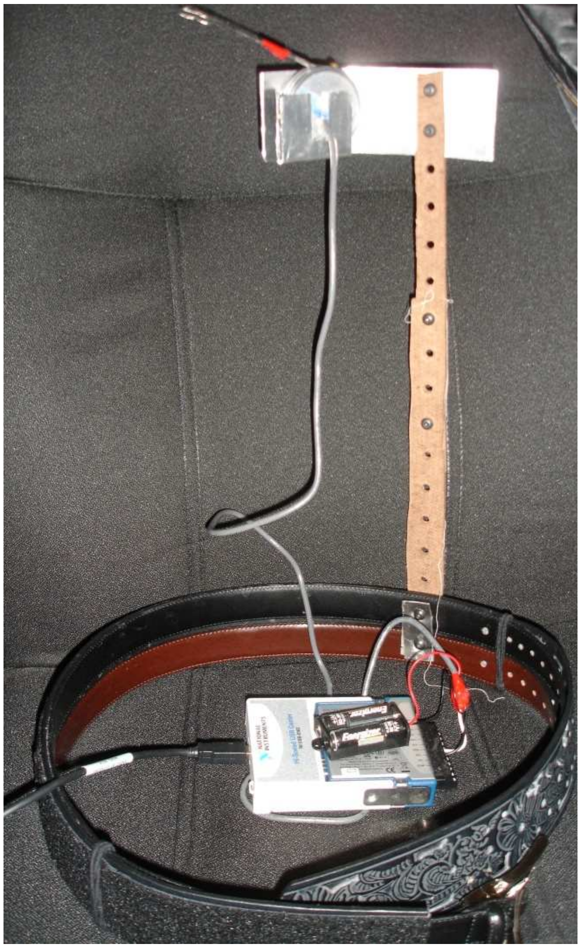


Figure 11: Belt attached to wooden strip and sensor

The potentiometer would be set up close to the 12th thoracic vertebra and would measure the distance moved by the 12th thoracic vertebra. The potentiometer would be powered through a DC volts battery and it would produce an output signal as its resistance would change. As a string potentiometer is used in this case, its resistance changes depending on the length of the string pulled out. The output signal would be analyzed using LabVIEW.

5.2 Evaluation of Design Alternatives

In order to choose the final design, the three design alternatives were evaluated based the team's objectives and constraints. The final design was to be one which met all the constraints and satisfied all the objectives.

To evaluate the designs, the objectives were weighed to determine the relative importance of each and the designs were then compared in a numerical evaluation method and a final design was chosen.

Table 1 is a pair-wise comparison chart which lists the objectives and evaluates the importance of each.

Table 1: Pairwise comparison chart

Objectives	**Comfortable**	**Accurate**	**Resize able**	**Compact**	**Safe**	**Score**
Comfortable	X	0	1	1	0	2
Accurate	1	x	1	1	1/2	3.5
Resize able	0	0	x	1	0	1
Compact	0	0	0	x	0	0
Safe	1	1/2	1	1	x	3.5
Total						10

1 – Indicates objective in the row is more important than the objective in the column

0 – Indicates objective in the column is more important than the objective in the row

½ - Indicates both the objectives are equally important

By comparing the objectives as shown in the table above, the objectives were ranked based on their scores. Table 2 shows how relative weights were assigned to each objective.

Table 2 – Relative Objective Weights

Objectives	Score	Adjusted Score	Weight
Comfortable	2	2 + 1 = 3	0.2
Accurate	3.5	3.5 + 1 = 4.5	0.3
Resize able	1	1 + 1 = 2	0.13
Compact	0	0 + 1 = 1	0.07
Safe	3.5	3.5 + 1 = 4.5	0.3
Total	10	15	1

The designs were then compared using the numerical evaluation matrix on their ability to satisfy the constraints specified at the commencement of the project. If the design was able to be completed on time and under budget, only then would we, be able to evaluate them. The numerical evaluation matrix shown below in Table 3; shows how satisfactorily each design meets the weighted objectives and whether it meets the constraints or not. In this table, the designs are rated on a scale of 0 to 1 depending on how well it satisfies the objective. A design which completely satisfies an objective is given a score of 1, if the objective is not satisfied at all, a score of 0 is given and a score of 0.5 is given to a design which meets the objective half of the time.

Table 3: Numerical Evaluation Method

Design Constraints and Objectives	Weight	Optical Mouse Sensor	Precision Potentiometers	String Potentiometer
O: Comfortable	20%	0.7 x 20% = 14%		0.7 x 20% = 14%
O: Accurate	30%	0.3 x 30% = 9%		0.9 x 30% = 27%
O: Resize able	13.33%	1 x 13.33% = 13.33%		1 x 13.33% = 13.33%
O: Compact	6.67%	0.4 x 6.67% = 2.67%		0.6 x 6.67% = 4%
O: Safe	30%	1 x 30% = 30%		1 x 30% = 30%
C: Budget ($300)			X	
C: Possible to build within the time			X	
C: Data Storage Capacity				
C: Measure stride length				
Total		69%		88.33%

5.3 Final Design Choice

From the numerical evaluation chart, it could be seen that while the design employing an optical mouse sensor met 69% of the design alternatives the design employing string potentiometers proved to be the best design as it met 88.33% of the design alternatives and satisfied all the constraints. The design using precision potentiometers was eliminated as it was a fairly complicated design which could not be built in the given time and would probably be outside of our budget limits. Therefore, the design using string potentiometer was chosen as the final design.

5.4 Detailed Presentation of the Final Design

A potentiometer is a device whose resistance changes with change in length. A string potentiometer looks like a yo-yo such that its resistance changes on pulling the string. The string potentiometer is set up such that the string stretches outward as the body moves forward while taking a stride in the transverse plane. The potentiometer has a linear scale and the length of the string pulled out varies linearly with its resistance. The potentiometer is powered by a fixed voltage source such as a battery and as its resistance changes; a change in output voltage is recorded. The output voltage forms the basis of our experiment and acts as an input signal to a data acquisition card and the data are analyzed on a computer using LabVIEW.

Figure 12: A string potentiometer

The setup involves a simple elastic belt which is attached to a light long piece of wood. Angular rotation of the spine is measured at the twelfth thoracic vertebra (T12) where maximum rotation is expected to be seen at the twelfth thoracic vertebra. At the end of the wooden piece is attached our string potentiometer which is enclosed in a case. This case also helps in putting the potentiometer at the right place so that the potentiometer is closer to the skin and the T12. The case can slide up and down of the wooden piece so as to accommodate people with different heights. Thus, as the subject walks, the T12 moves, which pulls out the string of the potentiometer, thereby changing the output voltage and the signal is generated.

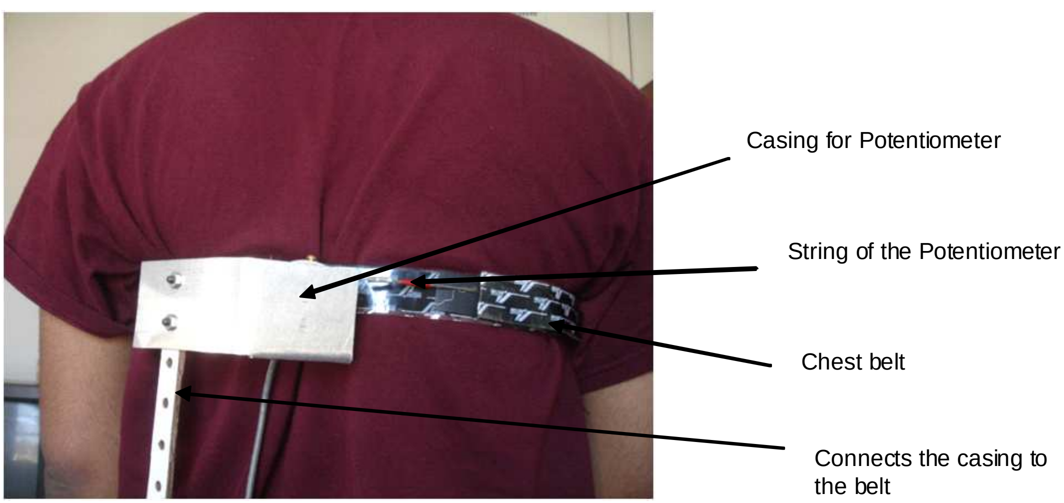


Figure 13: Positioning of the device on the back

The LabVIEW program designed includes several components for analyzing the data. The potentiometer is calibrated (as explained in appendix) and the potentiometer specs are used to calculate the distance moved by the string in the transverse plane. Before the readings are recorded the width of the back of each subject are recorded (as described in protocol and user guide). Using the width of the back and the distance moved by the back in the transverse plane, the angular rotation of the spine can be calculated by the formula:

$\theta = l/r$

Where, l is the distance moved by the back in transverse plane

r is half the width of the back (ie, from the center of the spine to the end of the potentiometer)

In addition to this, a trigger counter counts the peaks in the signals corresponding to the largest angle in each stride and gives the number of strides in the period when the data is being recorded. The LabVIEW program also calculates the maximum angle taken by a subject. This is done by a simple max function in Labview. The LabVIEW program yields out an excel spread sheet of data with continuous measurement of the angle of rotation where it is further analyzed. Also, MATLAB is used to analyze the data to calculate the angular velocity and the angular acceleration of the spine by differentiating the signal.

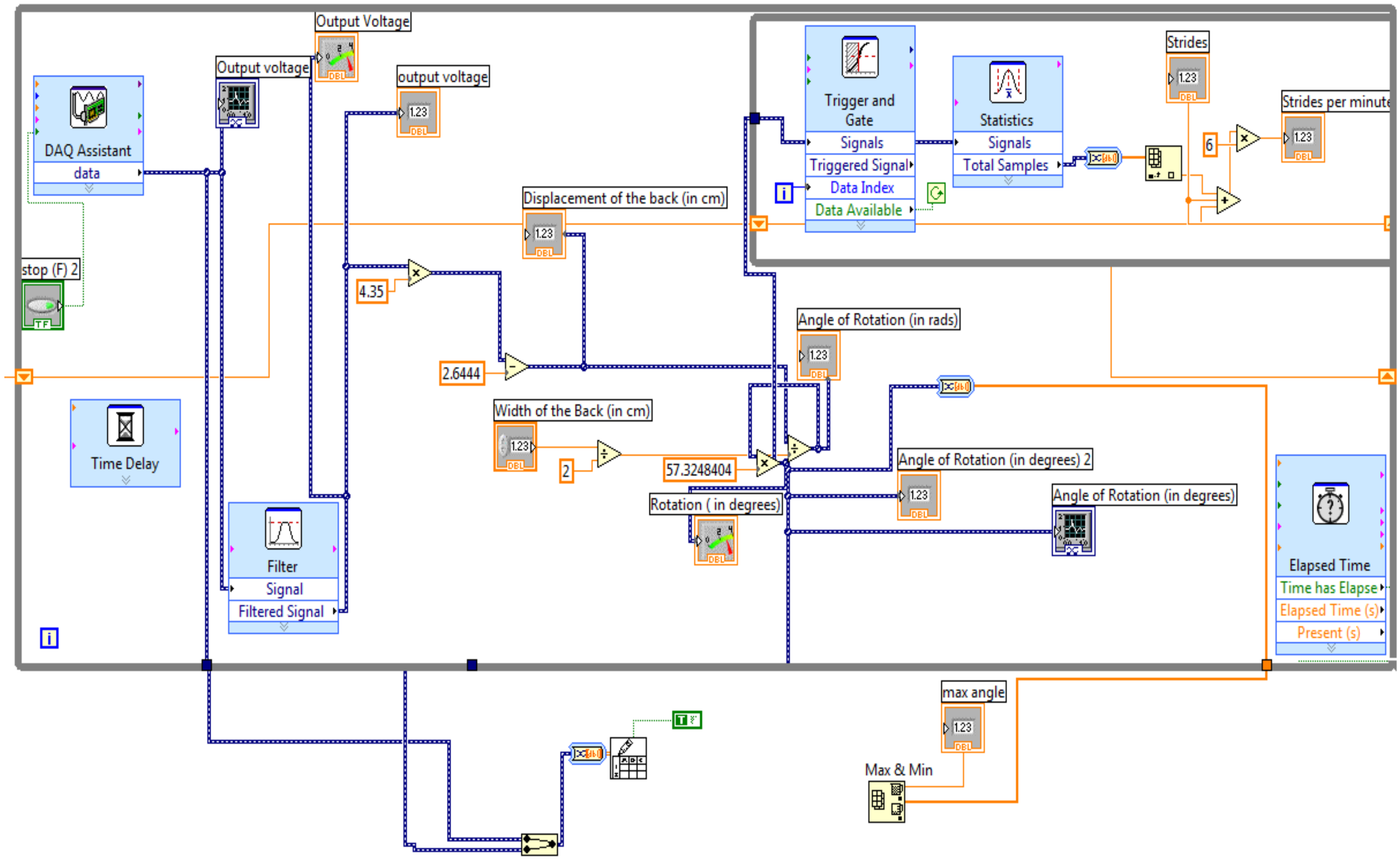


Figure 14: Block diagram in LabVIEW for calculation the angle

5.5 *Study Protocol*

Our experiment deals with examining the efficiency of gait in regular college students and comparing with the gait efficiency of other subjects who have undergone the therapy utilizing the core integration method provided at Bancroft school, Worcester. The efficiency of gait is quantized by measuring the torsional rotation of the spine while walking. Therefore, another part of our study involves coming up with an experimental setup which measures the rotation of the spine while walking.

Our proposed experimental setup consists of a string potentiometer attached to a belt which is worn around the hip. The follow steps are involved in our experiment:

- The subject is assigned an identification member.

- Subjects' personal information such as age, gender and frequency of physical activities are recorded and kept confidential.
- The subjects are given a detailed explanation of the experiment and how they are benefiting the research.
- After the subjects have given their consent, they are made to wear the belt.
- The subject is then made to walk on a treadmill.
- After a couple of strides, once the subject gets used to the setup, the signal is recorded by recording the change in resistance in the string potentiometer.
- The signal is recorded for 10 seconds.
- The output voltage from the string potentiometer which is varies as the subjects is walking is analyzed via a software program such as LabVIEW. The string potentiometer detects the displacement of the back in each stride at the level of the twelfth thoracic vertebra and converts it into a voltage signal. From the voltage signal, the displacement values and the angle of rotation can be calculated. For the support of the belt, a couple of Velcro strips are also attached to the subject’s thoracic area.

People undergoing the therapy involving the core integration method have experienced high reduction in pain and our study would provide a scientific proof for their results.

This study does not involve the subject to be on a particular diet and there are no drugs or chemicals used on them.

The technique is non invasive and the subject does not experience discomfort of any kind.

The privacy of all the subjects in maintained and the recorded personal information is not released to anyone other than the investigators.

6 Proof of Concept and Percentage Error

To test the accuracy of the device, the device was set up on a subject. This set up is the same as any other which was put on the subjects. It is shown below, a picture of the set up on a person when the person is standing straight. It should be noted that the string is not coming out of the string potentiometer and this will remain the reference point for the readings.

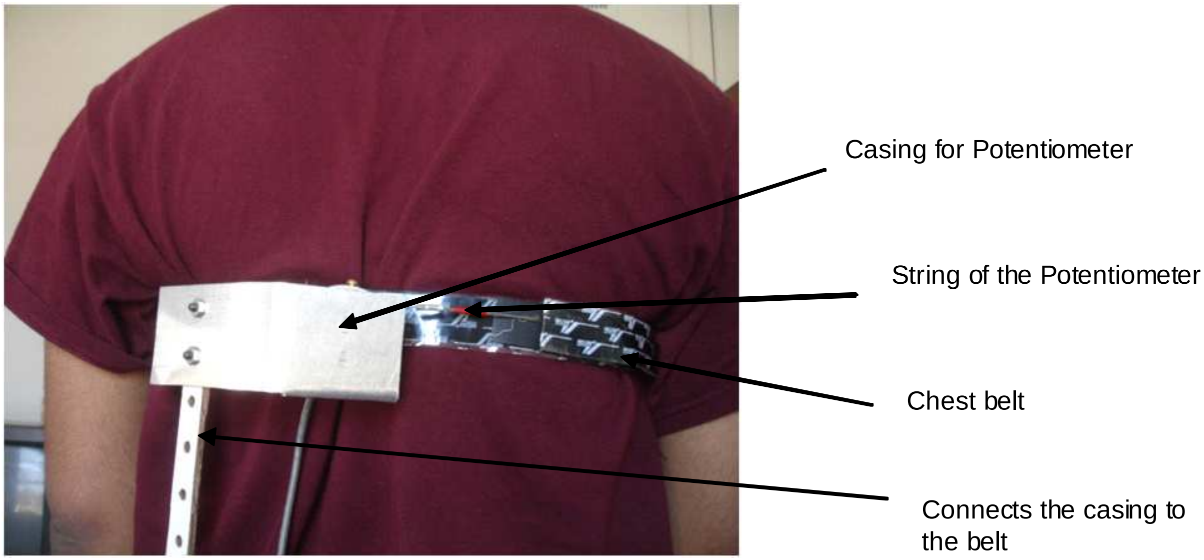


Figure 15: Subject with Back straight

The subject was asked to rotate his back and hold his position. At this position, the angle of rotation was recorded to be 25.37^0 by the Labview program.

Figure 16: Subject, when asked to rotate and hold

Also, at this position the angle of rotation was measured using a protractor. This protractor was held on the side, perpendicular to the back. The reference point on the back was a piece of paper which was attached to it. The other reference point stood stationary at a point when the back was not rotated. The measured angle of 26.5^0 is the angle between these points. Hence by comparing these measurements, we can conclude that the concept of the device works.

The percentage error can be measured by using the following formula.

%error = (true value - measured value) X 100 / true value

(26.5 - 25.37) X 100 / 26.5

= 0.043 X 100

% error = 4.3%

This error pertains to the angle measured. Also this procedure was done twice and for the second time, the percentage error was calculated to be 3.9%. The same subject was asked to rotate his back and hold his position. The measured angle was 21^0 and the Labview measured angle was 20.18^0.

The readings given by the LabVIEW program were based on a sampling rate of 1k for 10 seconds to obtain 10,000 data points.

The average percentage error of the angle measured was calculated to be 4.1%.

7 Results

In this study, angular rotation of the spine was measured and comparisons were made between two groups. Our control group was a group of college students who did not participate in any sports while our experimental group was a group trained in the Core – Integration method, who claimed to have more efficient gaits. Therefore, most of the subjects in control group did not perform any exercise, while all the subjects trained in the Core – Integration method were regular walkers. The subjects were made to walk at different velocities and it was also tested how the average angles, angular velocity, angular acceleration, stride rate and stride length was related to the velocity of the gait.

7.1 Consistency of Acquired Data

The acquired data needs to be consistent and reliable in order to use the readings for further analysis. In order to confirm this, a subject was asked to do the test with us twice, at different times but at the same speeds and similar conditions. It was hypothesized that, the acquired data are consistent, and both the graphs will overlap. As seen below, both the graphs do overlap consistently. The average max angle of both the tests is about the same. The plot in blue represents the change in angle when the readings were taken the first time and the red plot represents the second time. It can be observed that only a few strides had more angle of rotation in the 1st testing than the strides recorded during the second testing. Also, the number of strides taken in both the occasions is about the same. The second time,- the testing was done, the subject took one more stride than the first time.

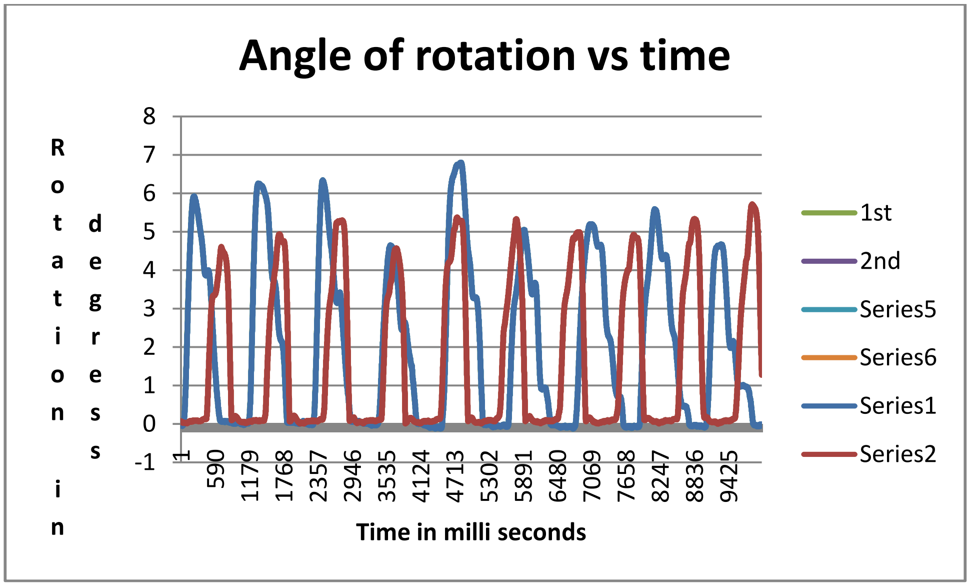


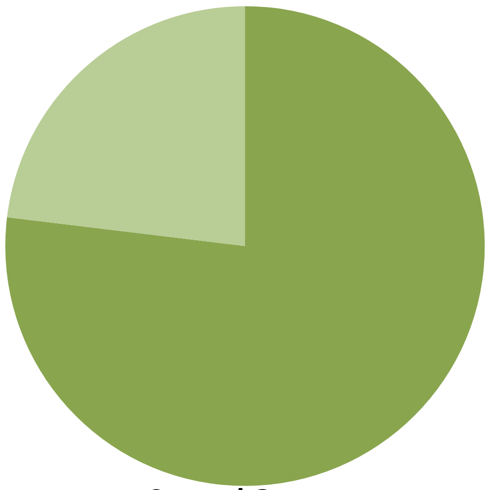
Figure 17: Graphical output of angles of rotation of a subject when measured at same speed at diferent times

Table 4: Parameters for comparison

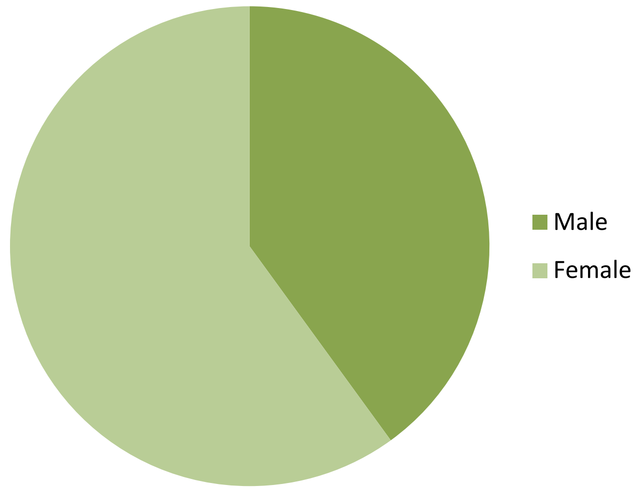
Considering this similarity in data when recorded twice under similar conditions, we conclude that the data being recorded is consistent. Table 4 sums up the various parameters which we use for the comparison of control groups. It should be noted that similar conditions mentioned above include the same device, protocol, dress of the subject, same day and same speed.

7.2 Variation in between Genders

The study includes people of both genders. To find out if there is any gender difference or a relation in the measured variables, such as angle of rotation and strides/min, we have plotted these variables. The pie chart below shows the gender distribution in the experimental and control group.



Control Group



Gender: Experimental Group

Pie charts of gender distribution in groups

At this point we will establish whether a difference exists in the data collected for men and women. Table 5 shows the averages recorded for the control group for males and females.

Table 5: Average angles of rotation

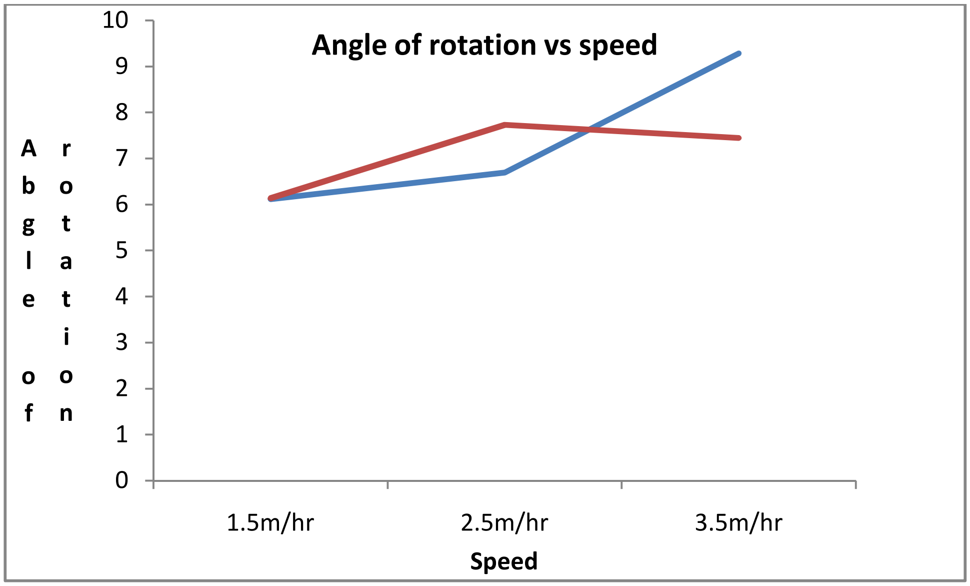


Figure 18: Angle of rotation at different speeds

The above shown graph consists of the average of the recorded angles of rotation for both men and women at different speeds. It is clearly visible that both the plots intersect each other and there is a consistent overlap.

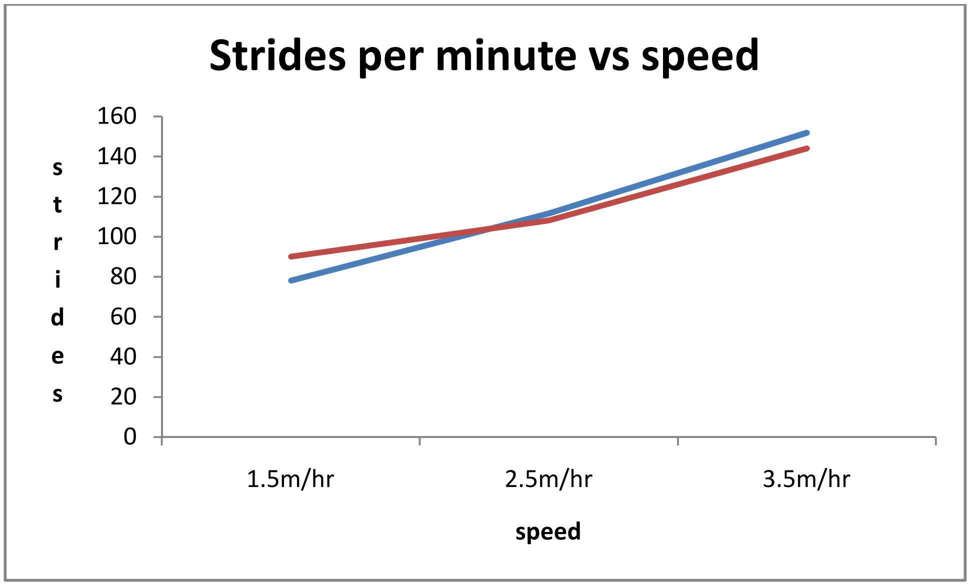


Figure 19: Strides per minute at different speeds

The graph shown above consists of the averages of strides per minutes at different speeds for both men and women. Clearly there is no significant difference in the averages at different speeds.

It can be concluded from the above analysis that there is no statistical difference between the data recorded for men and women. The other values used for analysis such as stride length, rate of change of angle of rotation and acceleration are all going to be assumed to be in the same range for both men and women. This is because these values are all derived from the previously analyzed angle of rotation and strides/minute. Hence from this point on, men and women will not be differentiated for the further analysis.

Table 6: t-test comparing angles of males and females

t-Test: Two-Sample Assuming Unequal Variances, Men and Women

	Variable 1	*Variable 2*
Mean	6.688	7.729095
Variance	10.38895	1.713814
Observations	11	4
Hypothesized Mean Difference	0	
df	9	
t Stat	-0.82046	
P(T<=t) one-tail	0.216574	
t Critical one-tail	1.833113	
P(T<=t) two-tail	0.433149	
t Critical two-tail	2.262157	

The T test performed between men and women above showed that the P value was greater than 0.05. This proved that there was no statistical difference between men and women.

7.3 Analysis of the control group and the experimental group

7.3.1 Angle of Rotation

In this part, our main hypothesis was tested. For the purpose of analysis, we included only the data obtained at 2.5 mph and 3.5 mph because the speed of 1.5 mph was too slow for the subjects and the angles obtained were random and not characteristic of their actual gait. Table 7 lists the angles recorded at two different speeds of 2.5 mph and 3.5 mph for both, the control group and the experimental group.

Table 7: Angles of Rotation of the Control and Experimental Group

	Control		Experimental	
Subjects	2.5mph	3.5mph	2.5mph	3.5mph
1	8.69	11.23	16.1	21.83
2	6.89	8.25	9.03	10.62
3	2.56	3	7.86	8.21
4	5.68	8.95	13.24	13.58
5	5.93	7.4	13.38	14.224
6	3.34	7.81	5.05	5.6
7	2.9	5.35	7.82	7.95
8	8.94	5.92	12.49	9.56
9	9.12	13.37	6.845	8.47
10	7.9	7.44	5.3	5.96
11	9.45	11.32	3.26	3.99
12	6.34	16.12	14.5	15.4
13	3.8	4.55		

Figure 20 shows the angle of rotation of the spine at two different speeds for the control group and Figure 21 shows the angle of rotation for the experimental group.

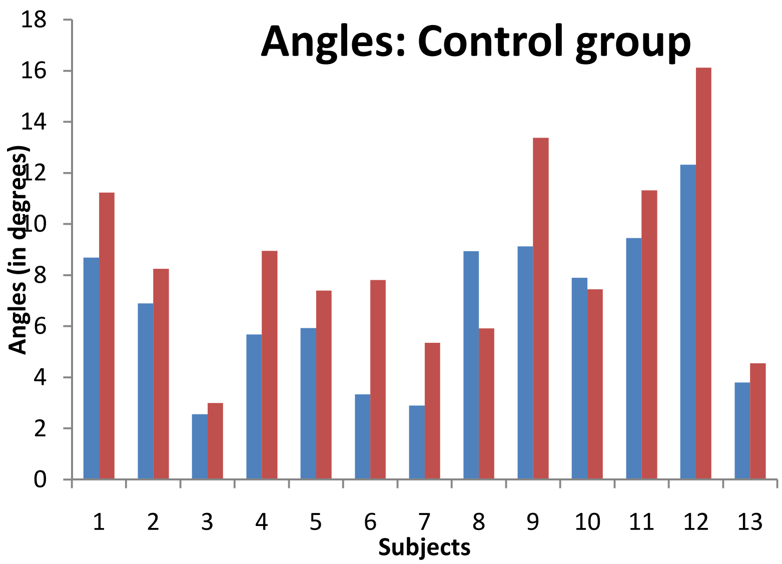


Figure 20: Angles of rotation at different speeds

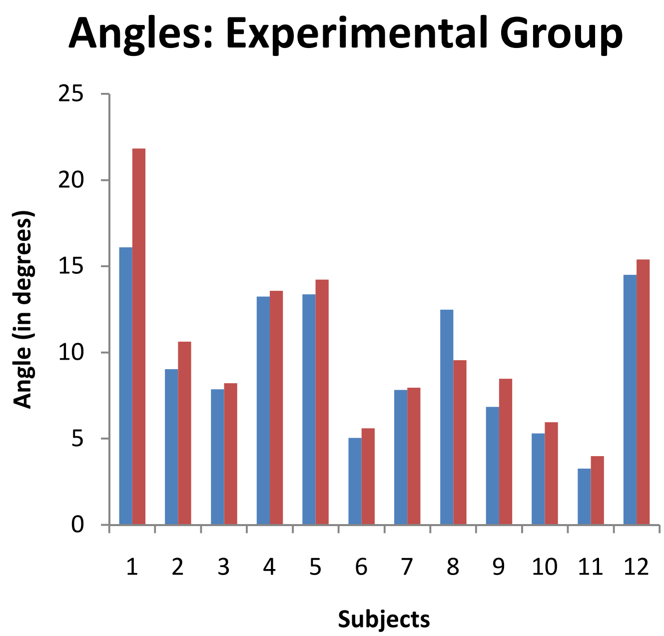


Figure 21: Angles of rotation for experimental Group

From these graphs, it can be seen at a glance, that the subjects of the experimental group have higher angles of rotation of the spine as compared to the experimental group. The angles of rotation of the two groups are further tested for any statistical difference by doing a t-test. The table below shows the results of the t-test done to compare the angles obtained for both the groups at 2.5 miles per hour.

Table 8: t-test comparing angle of rotation

t-Test: Two-Sample Assuming Unequal Variances

	control	*expt*
Mean	6.927692	9.572917
Variance	8.284603	17.78548
Observations	13	12
Hypothesized Mean Difference	0	
df	19	
t Stat	-1.817	
P(T<=t) one-tail	0.042513	
t Critical one-tail	1.729133	
P(T<=t) two-tail	0.085025	
t Critical two-tail	2.093024	

From the results of the t-test, it can be seen that a definite statistical difference exists between the angles of rotation of the two groups. The mean angle of the experimental group is about 2.7

degrees more than the mean of the control group. The p-value is lesser than 0.05, therefore, the test results are significant at the 95% confidence level. Also, the variance of the experimental group is much more than the control group. It can be concluded that a definite statistical difference exists between the two groups with 95.75% surety as is indicated by the p-value. A t-test done to compare angular rotation values at 3.5 miles per hour also gave similar results indicating a statistical difference.

7.3.2 Trends in average angles with velocity

For the control group, it was also observed how the average angle of the spine changed while walking at different speeds. For this, the members of the control group were made to walk at three different speeds; a stroll of 1.5 miles per hour, one being a comfortable walking speed of 2.5 miles per hour and a brisk walk at 3.5 miles per hour.

It was observed that the subjects had varied angles at 1.5 miles per hour which were random in relation to their angles at higher speeds. The angles increased as the velocity of the treadmill was increased from 2.5 miles per hour to 3.5 miles per hour. This is illustrated by Figure 22 below; the dark black line gives the average velocity of all the subjects.

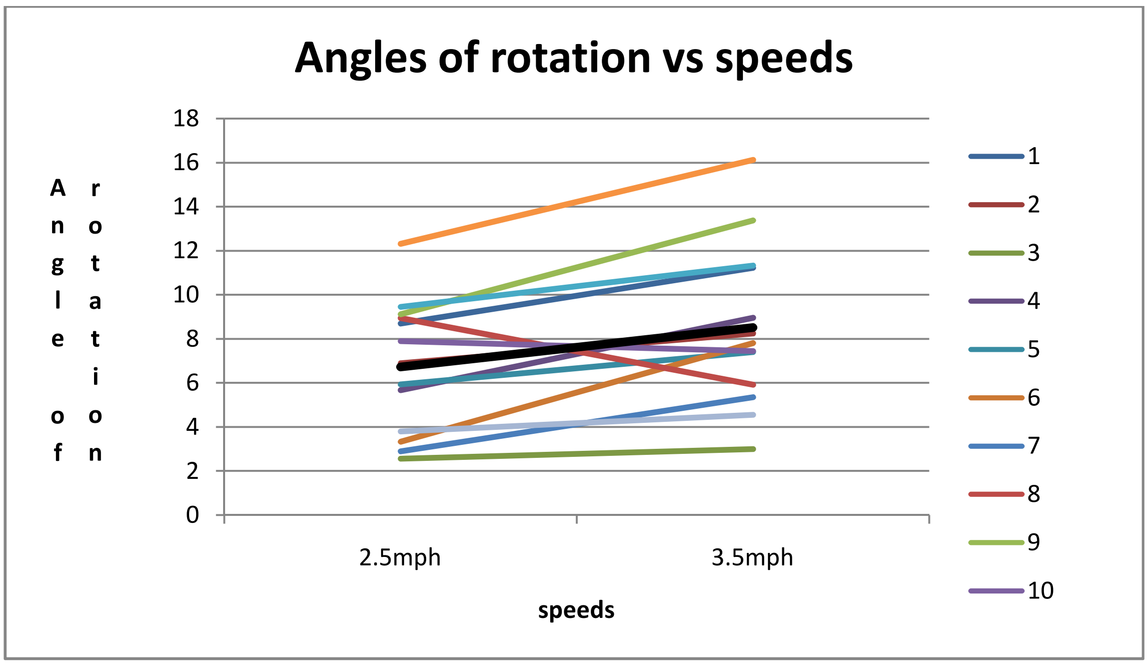


Figure 22: Comparison of angles at two speeds – Control Group

As seen in the above graph, the angles of #8 decreases with speed. This could be either characteristic of the subject's gait, which may be because the subject is uncomfortable walking at higher speeds or it could be bad data. Getting rid of the subject the graph and the mean change is shown in Figure 23.

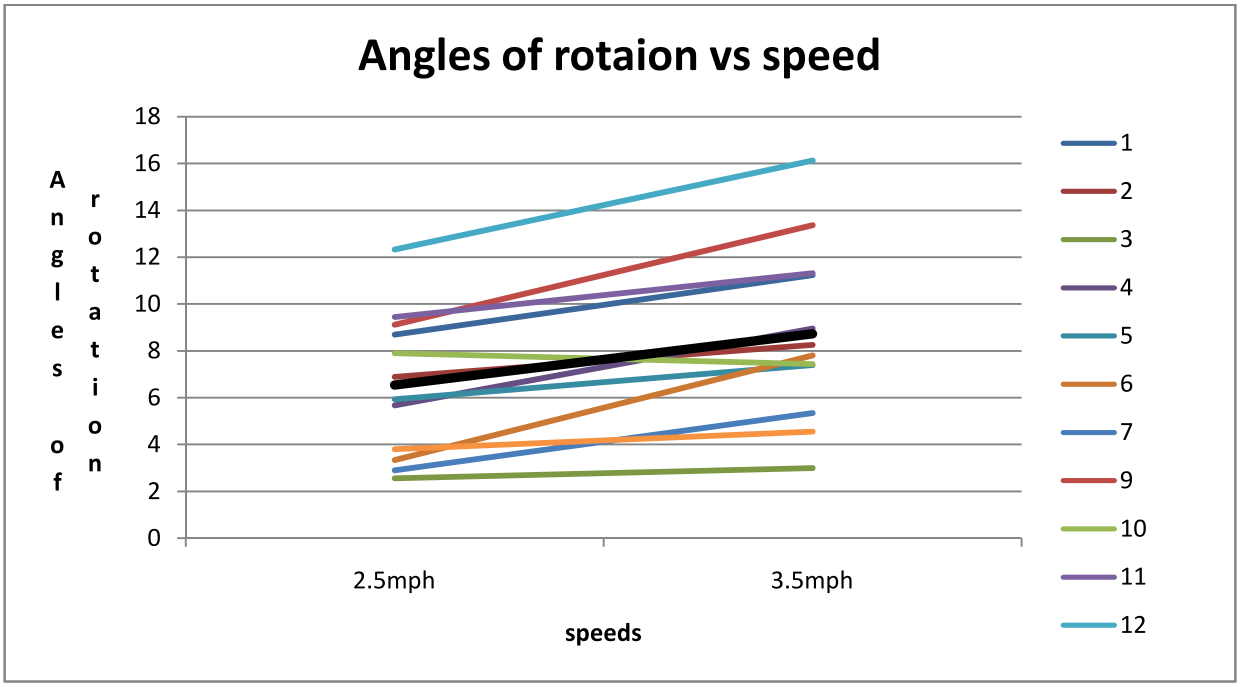


Figure 23: Comparison of angles - Corrected Data

Figure 24 shows the variation of spinal rotation with speed of the experimental group. In this case too, it was observed that the angle increased with speed on an average, although the increase was more consistent.

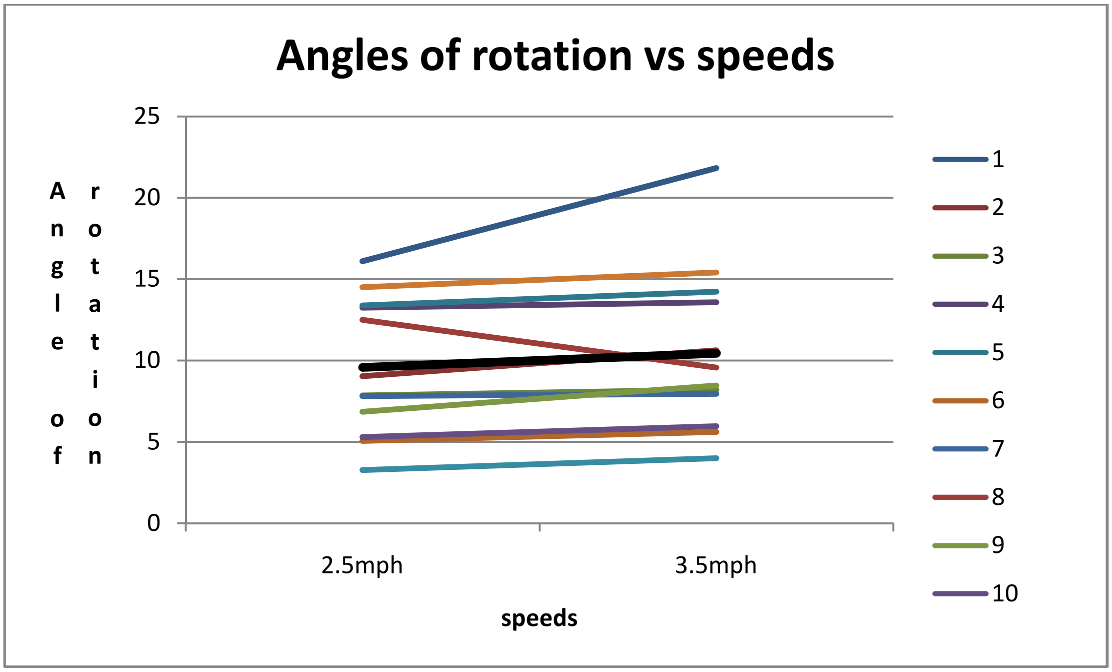


Figure 24: Comparison of angles at two speeds – Experimental Group

As seen in the above graph, the angles of #8 decreases with speed. This could be either characteristic of the subject's gait, which may be because the subject is uncomfortable walking at higher speeds or it could be bad data. There are more chances of this being bad data as the experimental group was comfortable walking at higher speeds. Getting rid of the subject the graph and the mean change as shown in Figure 25.

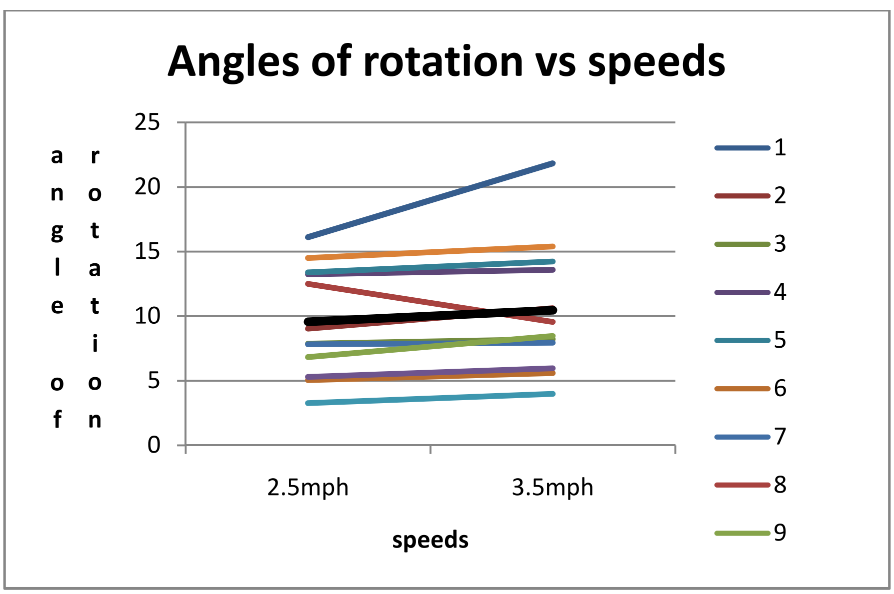


Figure 25: Comparison of angles with speed - Corrected Data

7.3.3 Angular Velocity

Using MATLAB, the angle of rotation values were differentiated with respect to time to give the angular velocity vs time. The angular velocity was calculated for each subject in both the groups at both the speeds. Table 9 shows angular velocities for both the groups at each speed.

Table 9: Angular velocities of both the groups

	Angular Velocity (in degrees / s)			
Subjects	Control Group		Experimental Group	
	2.5 mph	3.5 mph	2.5 mph	3.5 mph
1	1.72	3.47	5.83	8.67
2	1.26	1.29	3.96	6.83
3	1.16	2.28	15.94	12.99
4	4.49	5.90	6.70	0.68
5	2.02	3.26	6.01	7.72
6	2.73	4.31	3.50	4.93
7	3.64	5.69	8.49	9.96
8	2.34	3.49	5.24	8.87
9	1.73	3.78	7.22	8.96
10	0.88	4.95	7.25	8.51
11	4.31	5.44	6.06	7.03
12	1.23	8.83	1.61	2.34
13	3.22	2.57		

In the table, it can be seen that the 4th subject of the Experimental Group had a reading which was inconsistent with the other readings. This could be due to erroneous measures and other external errors.

Furthermore, a t-test was done to test for a statistical variation between the angular velocities of the two groups at a gait velocity of 2.5 miles per hour.

Table 10 summarizes the results of the t-test. A t-test at a gait velocity of 3.5 miles per hour had similar results.

Table 10: t-test comparing angular velocities

t-Test: Two-Sample Assuming Unequal Variances

	Control	*Experimental*
Mean	2.362792	6.926209091
Variance	1.490607	11.00328787
Observations	13	12
Hypothesized Mean Difference	0	
df	12	
t Stat	-4.32176	
P(T<=t) one-tail	0.000497	
t Critical one-tail	1.782288	
P(T<=t) two-tail	0.000993	
t Critical two-tail	2.178813	

From the table, it can be seen that that the p-value is very small and there is a clear difference in the mean angular velocity of the two groups. In this case too, the variance for the experimental group was very high and very low for the control group. Thus, it can be concluded that the angular velocities of the control and the experimental group were statistically different with the experimental group having a higher angular velocity than the control group.

7.3.4 Angular Acceleration

MATLAB was also used to calculate the angular acceleration, by further differentiating the angular velocity values. Table 11 lists the angular accelerations of both the groups at 2.5 mph and 3.5 mph.

Table 11: Angular acceleration of both the groups

	Angular Acceleration (in degrees/s^2)			
Subjects	Control group		Experimental Group	
	2.5 mph	3.5 mph	2.5 mph	3.5 mph
1	1.50	2.91	6.29	8.36
2	1.24	1.30	3.56	8.41
3	1.13	2.05	24.28	20.05
4	4.56	6.25	11.02	0.85
5	2.00	3.53	9.04	11.66
6	2.10	5.21	3.62	7.03
7	3.98	5.91	12.17	16.54
8	1.67	2.50	7.62	12.76
9	2.31	4.69	10.69	14.82
10	0.68	7.52	11.12	11.26
11	5.06	6.15	5.36	7.33
12	0.83	13.57	2.50	3.54
13	4.72	3.51		

In the table, it can be seen that the 4th subject of the Experimental Group had a reading which was inconsistent with the other readings. This could be due to erroneous measures and other external errors.

A t-test was performed to check for statistical difference in the angular accelerations of the two groups at a gait velocity of 2.5 miles per hour. Table 12 summarizes the results of the t-test. A t-test done at a gait velocity of 3.5 miles per hour gave similar results.

Table 12: t-test comparing Angular Acceleration

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	2.444662	9.524390909
Variance	2.466511	33.29455545
Observations	13	12
Hypothesized Mean Difference	0	

df	11
t Stat	-3.94752
P(T<=t) one-tail	0.001141
t Critical one-tail	1.795885
P(T<=t) two-tail	0.002282
t Critical two-tail	2.200985

From the table, it can be seen that two groups differ markedly in the angular acceleration as well, with the experimental group having higher angular acceleration than the control group. As for the cases of angles and angular velocity, the experimental group also has a much higher variance than the control group. It can be concluded that the angular accelerations of the two groups differ statistically with the low p-value of 0.001.

7.3.5 Trends in strides per minute with velocity

The control group's strides were also recorded and compared at two different speeds of 2.5 miles per hour and 3.5 miles per hour. The strides per minute were seen to increase with speed for all the subjects; however they increased by different amounts. In some the increase was drastic whereas in others it was more subtle. This can be associated with the fact that some people overcome larger speeds by taking longer strides while others do so by taking more number of steps. Table 13 lists the strides per minute of the control and the experimental group.

Table 13: Strides per minute of both groups

Subjects	Control Group		Experimental Group	
	2.5mph	3.5mph	2.5 mph	3.5 mph
1	108	144	108	132
2	108	150	120	144
3	78	90	156	168
4	108	168	144	156
5	102	186	132	132
6	120	156	120	144
7	114	168	120	132

8	120	144	132	144
9	150	180	120	144
10	102	132	108	120
11	108	126	120	132
12	120	150	132	144
13	120	168		

Figure 26 shows the stride rates of the control group at two different speeds.

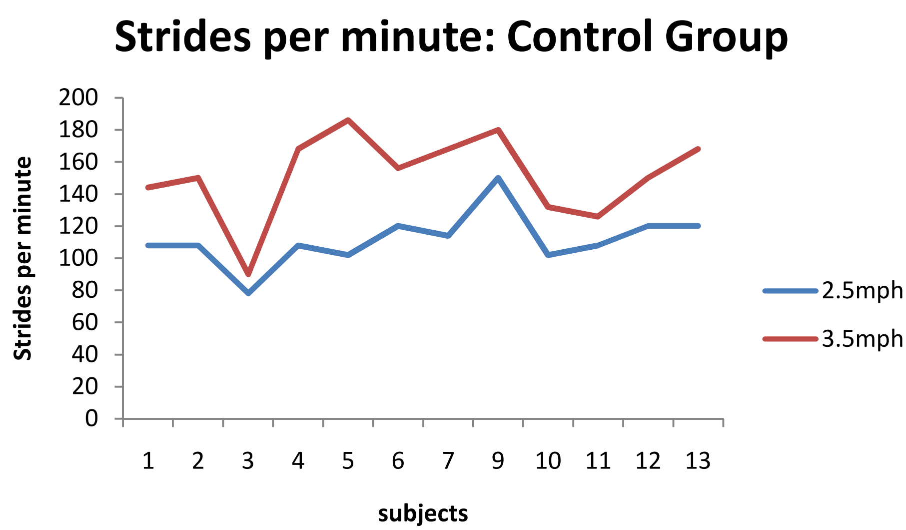


Figure 26: Strides per minute of Control Group

Figure 27 shows the strides per minute of the experimental group. In this case also, it can be seen that the stride rate increased at higher gait velocity.

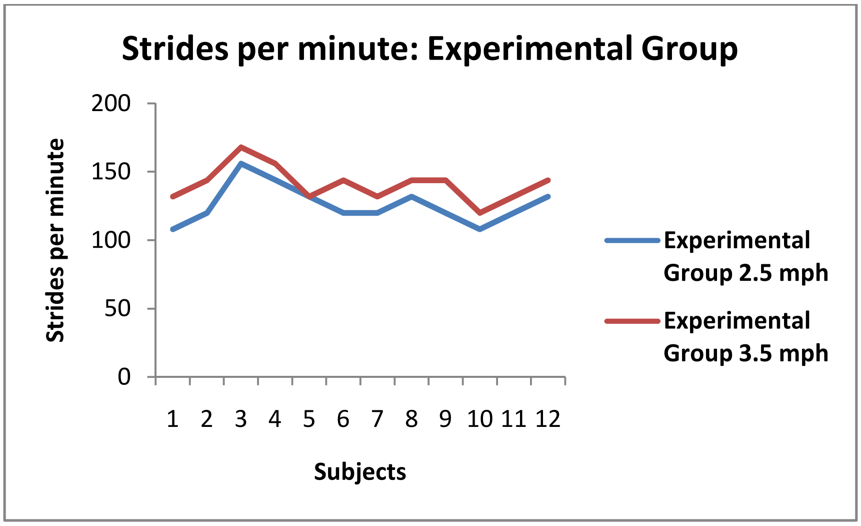


Figure 27: Strides per minute of Experimental Group

To test whether a statistical variation was present between the stride rate of both the groups; a t-test was done to compare the strides at 2.5 miles per hour. The results of the t-test are summarized in Table 14.

Table 14: t- test comparing stride rates of both the groups

t-Test: Two-Sample Assuming Unequal Variances

	control	*experimental*
Mean	112.1538	126
Variance	260.3077	196.3636364
Observations	13	12
Hypothesized Mean Difference	0	
df	23	
t Stat	-2.29538	
P(T<=t) one-tail	0.015583	
t Critical one-tail	1.713872	
P(T<=t) two-tail	0.031165	
t Critical two-tail	2.068658	

From the table, it can be concluded that since the p-value is lower than 0.05 a statistical difference exists and the experimental group on an average had a higher stride rate compared to the control group.

7.3.6 Trends in Stride Length with velocity

It was also seen how increasing the speed of the gait affected the stride length. Table 15 lists the stride lengths of both the groups at 2.5 miles per hour and 3.5 miles per hour.

Table 15: Stride length of both the groups (in meters)

	Stride length (in meters)			
Subjects	Control		Experimental	
	2.5 mph	3.5 mph	2.5 mph	3.5 mph
1	0.62	0.65	0.62	0.71
2	0.62	0.62	0.56	0.65
3	0.85	1.04	0.43	0.56
4	0.62	0.56	0.46	0.60
5	0.65	0.50	0.51	0.71
6	0.56	0.60	0.56	0.65
7	0.58	0.56	0.56	0.71
8	0.56	0.65	0.51	0.65
9	0.44	0.52	0.56	0.65
10	0.65	0.71	0.62	0.78
11	0.62	0.74	0.56	0.71
12	0.56	0.62	0.51	0.65
13	0.56	0.56		

In case of the control group, our studies did not show a consistent relationship between the two parameters. As shown in Figure 28, the stride length increased with increasing speed for most people, it also decreased for some others. This can be attributed to that fact, that while some people overcome large speeds by taking longer strides, others do it by taking more number of steps. It was also seen that the subjects whose stride lengths decreased at higher speeds, had a smaller increase in strides per minute at higher speeds compared to the subjects whose stride lengths increased with speed. Therefore, although the control group showed an increase in stride rate with speed, a similar observation was not made in case of stride length.

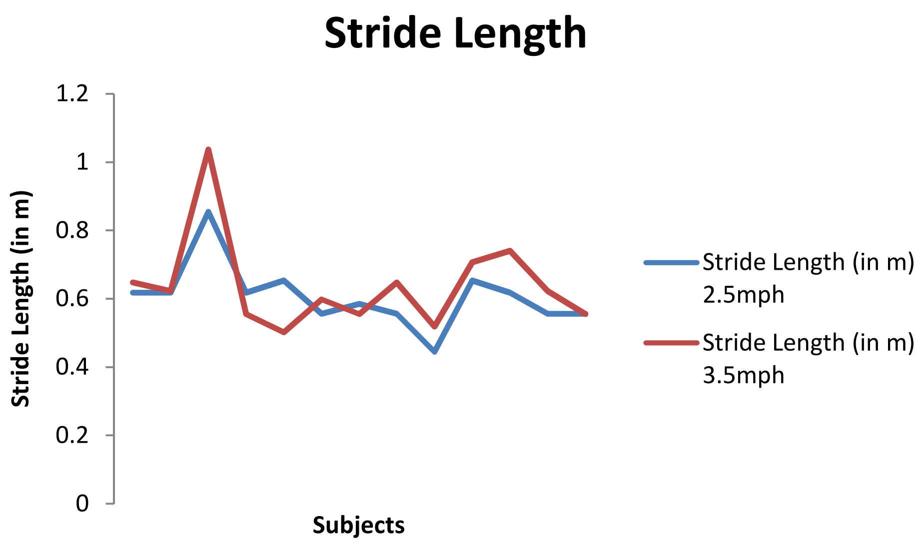


Figure 28: Stride Length of Control Group

In case of the experimental group, the stride length was seen to increase with gait velocity. This is because all the subjects of the experimental group were trained in the Core integration method and had similar gaits. Thus, they all responded to increase in speed in the same way. This is shown in Figure 29.

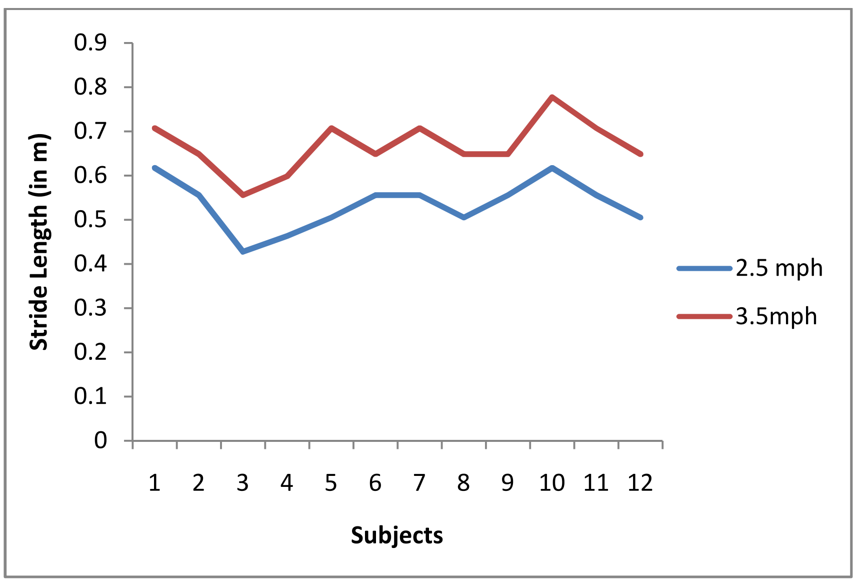


Figure 29: Stride Length of Experimental Group

The stride lengths of both the groups were compared at a gait velocity of 2.5 miles per hour by performing a paired t-test to test for statistical variation. The results are summarized in

Table 16.

Table 16: t-test comparing stride lengths of both groups

t-Test: Two-Sample Assuming Unequal Variances

	Control	*Experimental*
Mean	0.606376	0.53484429
Variance	0.008636	0.00319325
Observations	13	12
Hypothesized Mean Difference	0	
df	20	
t Stat	2.345107	
P(T<=t) one-tail	0.014725	
t Critical one-tail	1.724718	
P(T<=t) two-tail	0.02945	
t Critical two-tail	2.085963	

It can be concluded that the experimental group has a lower stride length as compared to the control group at the same gait velocity. This is confirmed by the low p-value of 0.01.

7.3.7 Regression Analysis

Various regression analyses were done to test whether the angular velocity and angular acceleration were dependent on speed. However, this testing was not statistically significant enough to establish a definite relationship. This is because the subjects were tested at only 3 different speeds. As previously tested, the angle of rotation is seen to increase with the speed .Moreover, the regression analyses were done only for the control group as data was available at three different speeds only for the control group. The experimental group was tested at only 2 speeds, which was not enough to establish a definite relationship.

A regression analysis of angular velocity with respect to gait velocity gave an R^2 value of 0.925 as shown in Figure 30. Based on this data, it can be said that the angular velocity is dependent on the gait velocity and increases as the speed of walking increases.

Below are the average angular velocity values of the control group at the three different gait velocities.

	1.5 mph	2.5 mph	3.5 mph
Average	1.72	2.29	3.99

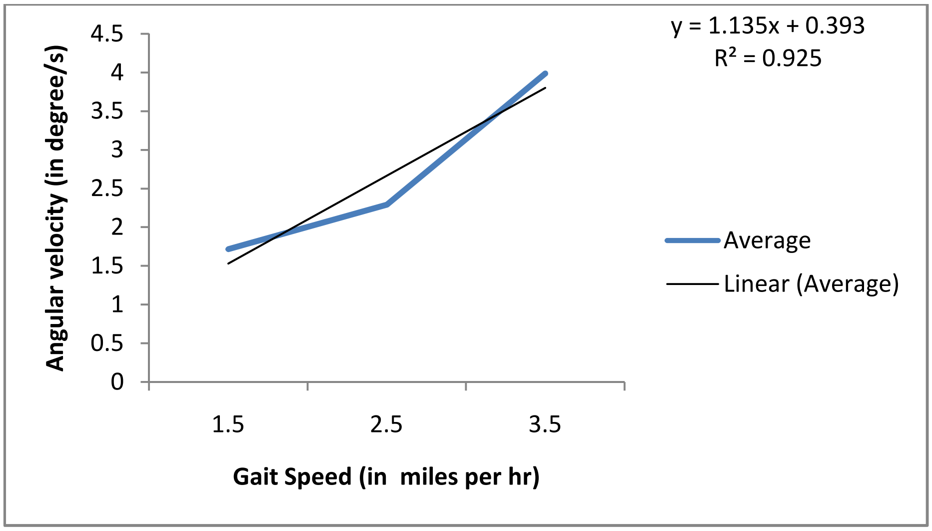


Figure 30: Angular Velocity vs Speed

A regression analysis was also done to test the dependence of angular acceleration with gait velocity. This analysis gave an R^2 value of 0.908. This also indicates that the acceleration is dependent on the gait velocity and increases as gait velocity increases. However, the subjects would be needed to be tested at more speeds to say that with enough confidence as three speeds are not enough. Below are the average angular values of the control group at the three different gait velocities.

	1.5 mph	2.5 mph	3.5 mph
Average	1.64	2.25	4.36

Figure 31 shows the dependence of angular acceleration on gait velocity.

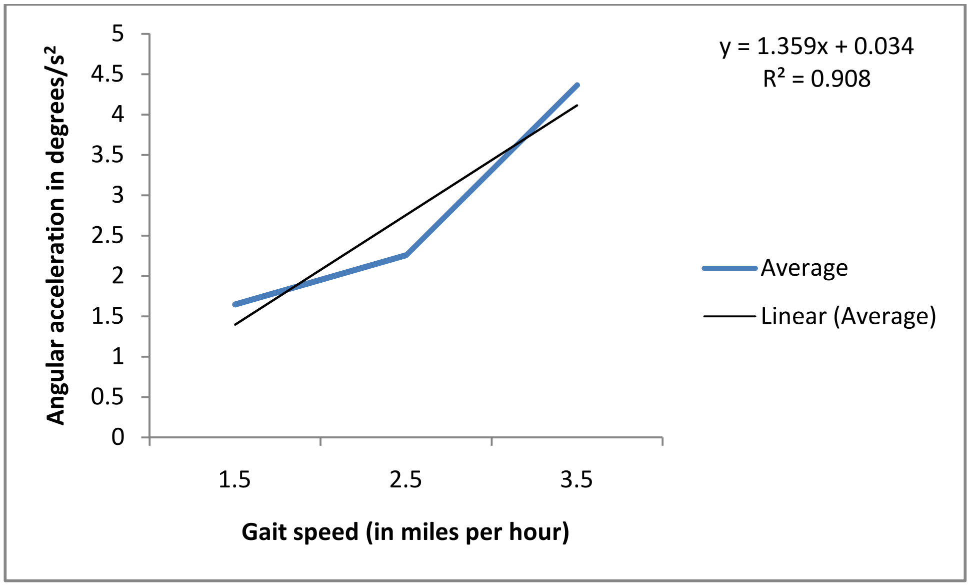


Figure 31: Angular acceleration vs speed

A regression analysis was also done to test the dependence of stride length of the control group on gait velocity but it gave a very low R^2 value which led us to conclude that there was no dependence between the two. While some subjects took longer strides at higher speeds, others compensated for the increased speed by taking more steps in that period of time. Although some studies, show that stride length depends on gait velocity, our study did not indicate this which could be due to the measurements made at only 3 different speeds.

8 Conclusion

In our study, the angular rotation of the spine was measured using a string potentiometer and an experimental group consisting of subjects trained in the Core Integration method taught by Josef DellaGrotte were compared with a control group. The members of the experimental group claimed to have more efficient gait as they rotated their spines more than most people. This was proved in our testing as the control group had an average angle of 6.9^0 was opposed to 9.6^0 of the experimental group.

The device designed was sensitive up to a percentage error of 4.1% and was consistent in its measurements. It was determined whether the angular rotation had different values among both the sexes.

The measurements were made at three different speeds of the treadmill, namely, 1.5 mph, 2.5 mph and 3.5 mph and the angle of rotation, angular velocity, angular acceleration, strides per minute and stride length were calculated and compared at the three speeds. On an average, the angles of rotation and strides per length increased as the speed of the treadmill increased. In the control group, the stride length did not seem to have a significant dependence on gait velocity. This could be accounted for by the fact that, while some subjects took longer strides as the velocity increased, others took more steps of shorter stride length. However, the stride length was seen to increase with gait velocity in the experimental group as all the subjects in this group has a similar gait as they were trained under the Core Integration method. The angular velocity and acceleration were also seen to increase with gait velocity, and their dependence was tested by doing a regression analysis. Although, the test showed that there is a relationship, this outcome was not significant enough to establish a definite relationship as the readings were taken at three different speeds only.

Table 17 summarizes the means of angles of rotation, angular velocity, angular acceleration, stride rate and stride lengths of both the groups at two different speeds.

Table 17: Summary of data obtained in both the groups

	Control Group		Experimental Group	
Gait Velocity	2.5 mph	3.5 mph	2.5 mph	3.5 mph
θ (in degrees)	6.3	8.5	9.6	10.4
θ' (Angular Velocity) – in degrees/s	2.4	4.3	6.5	7.3
θ'' (Angular Acceleration) – in degrees /s^2	2.4	5.0	8.9	10.2
Stride rate (in strides per minute)	112	151	126	141
Stride Length (in meters)	0.6	0.6	0.5	0.7

Paired t-tests were done to account for statistical difference in angles, angular velocity, angular acceleration, stride rate and stride length. It was observed that the experimental group had higher angles, angular velocity, angular acceleration, stride rate than the control group. Having a higher angle of rotation did not imply higher angular velocity and angular acceleration; this statistical difference probably arose because the experimental group had an altogether different gait. This could be further proven by measuring the rotation at the 6^{th} thoracic vertebra but could not be achieved by the present design and could be implemented in the future in the design.

9 Future Recommendations

The device is in its early stages. In the current device the technique used to adjust the height of the potentiometer, though effective, is time consuming. Perhaps, a future group could manufacture a sliding mechanism using which the height adjustment would be easy and use less of the subject's time for the testing procedure.

Also the type of potentiometer used in the current setup is a string potentiometer. Though all potentiometers would establish the same task, a linear extension potentiometer would make the device more compact and also make the device withstand more wear and tear. A string potentiometer is more bulkier and also is prone to damage with certain kind of gaits involving a lot of vertical movement.

Another advantage of using a linear extension potentiometer is that it will make the casing smaller and hence forth the device lighter. Also the material used for the casing in this setup is aluminum and perhaps a lighter metal can replace aluminum by a future project group.

The Velcro belts used in the setup have proven to work fine but sometimes they tend to slip down and change position when put on clothes made of certain soft materials. A future group can manufacture a light weight adjustable belt to replace the Velcro strapping.

For women, to avoid discomfort, strappers have been used to attach the string of the potentiometer to the skin. This method gave the group results with reasonable accuracy but a future project group can devise a better and less complicated method.

The advantages of a larger sample size include the exclusion of data outliers. The sample sizes taken in this study are of reasonable size but larger sample sizes will equip the project group to make more observations. Various possible factors which can affect the analysis such as gender difference, age difference, daily routines and walking frequency will all be excluded in a larger sample.

To be better able to conclude the results of the study, a group of people should be tested before and after they have training with the Core Integration Method and this study should be double blinded to acquire more efficient results. A double blinded study will eliminate any prejudiced opinions on how the results should be like.

In the future, a device using the same principle can be fabricated which can work with wireless technology. This will enable the group to take readings while people walk on ground rather than on a treadmill which might cause inconvenience to some.

A more compact set up can be designed for the ease of use and also a setup which can enable the use of the device by the subject himself will be helpful. This will make it possible for anyone to use the device by themselves to measure their spinal rotation. The present technique requires 2 investigators to assist a subject.

To compare the groups better, measurements of spinal rotation can be taken at more places. For example, rotation can be measured at T6 and T8 which will add to the accuracy of the analysis. At times, the rigidity of the device gave the team problems in taking readings. Perhaps a better model and a different material to build the device can be done in the future.

10 Institutional Review Board Regulations

The IRB establishes regulatory requirements and the ethical guidelines for research involving human subjects. They aim to make the investigators or researchers understand and comply with these regulations. IRB's overall goal to is to support the conduct of research which protects and promotes the rights of human subjects. The Common Rule, 45 CFR 46 and WPI policy require that the WPI Institutional Review Board (IRB) review and approve all applicable studies involving human subjects performed at WPI. These applicable studies also include engineering projects such as ours. There are certain categories of research which can be exempted form review according to law but even these decisions are made by the IRB. Either reviewed or exempted, every research on campus involving humans will go through the IRB.

The approval from the IRB should be received before the study has begun. Each application will include a PI (Principal Investigator) who holds primary responsibility for the application. The PI educates the IRB about the application and documents risks and benefits of the research activity. In our study the PI include the projects partners Rohit Jagini and Ananya Tandon. During the entire application process, the applicant works with the IRB to develop, document an ethically responsible investigation.

The project group submitted an application for expedited review from the IRB. The group documented and complied with certain IRB review standards. These standards include

- proposed research will not pose any threat to the subjects
- informing the subjects the importance and the scientific benefit of the study
- informing the risks involved, level of discomfort involved
- subject selection is equitable as in number of males and females involved and is the subject selection appropriate for the protocol

In the appendix is attached our informed consent form in which all the above points are discussed and informed in detail. It informs the subjects of the possible risks involved, their probability, our safety precautions because of the voltage and battery source being involved in the setup. A 3V battery setup is used and the chances of a macro shock are very minimal. Also an investigator will stand by all the time for assistance. In the consent form, the advantages of their participation are mentioned which is to establish if the Core Integration Method practitioners have more spinal rotation which is a principal factor in walking efficiency. The minimal discomforts involved in the study which includes the wearing of the device are scripted. Also the procedure involving the maintenance of subject confidentiality which is to assign serial numbers to each of the subjects and the use of these numbers as reference for further analysis was mentioned.

11 Ethical Issues

A common ethical issue faced by designers in almost all fields is the liability issue. The device if fails because of unexpected reasons, the designer will be liable for the repercussions. Because the device deals with the measurement of the rotation of the spine, there are no life threatening risks involved. Bur the reliability of the device is very important as the conclusions made from the study will be reported. Care was taken by the design group to make the most reliable device possible. The proof of concept testing made sure the device works with reasonable accuracy and precision.

The String Potentiometer is an important part of the device. Permission will be needed to literally include a certain company's String Potentiometer directly into the device and not acknowledge it anywhere in the report. This might be an ethical issue. The String Potentiometer reading holds the key to the success of the functioning of the device. If the reading is shown wrong then the calibrated angle will be wrong. For this reason a safety method was included in which the teeam periodically performed the test twice on the same subject under similar conditions keeping into consideration the expected range of data values. The Potentiometer was not seen failing till yet but may be a reason for an ethical issue in the future if it fails after using the device multiple times on several subjects. This aspect of the device cannot be tested now as it is out of the scope of the project.

A considerable amount of research had been done by the design team to be familiar with the present techniques used to the spinal rotation of the spine during gait. Invariably certain ideas from these various designs were referenced and adopted for our design. The problem of intellectual property comes up and this another major ethical issue. Very few devices have been engineered so far to measure the spinal rotation and hence few devices were available for reference. Further research and proper referencing of all the techniques adopted by the team have been reported which can be an ethical issue of not reported.

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13 Appendix

13.1 Bill Of materials

Quantity	Material	
1	String Potentiometer	
3	Belts	32.92
1	Suspenders	5.83
1	Vecro 4'x2 in	12.99
1	Tape 3ft	6.99
1	Stick & Seal Glue	2.88
1	Velcro 4ft	8.97
1	Velcro Tape	6.97
1	Screws 11"	2.29
2	Springs	6.87
2	Copper plates	6.3
1	Krazy Glue	2.89
1	Mounting Tape	3.69
1	Graphite Sticks	2.98
1	Charcoal Set	1.05
1	Rib Non Roll	1.79
1	Elastic	2.99
1	Velcro Coins	2.99
1	Spring Assortment	3.97
1	Nuts	2.39
	Total	117.75
	Total With Taxes	**121.1**

13.2 Specifications

Device

Adjustable Device Length: 14 inches

Range of Device Length: 13.5 inches - 27.5 inches

Device weight: 2.5 pounds

Range of waist sizes for which the device can be used on : 26"in - 40"in

Accuracy:

Maximum Measurable Angle: Varies with width of back, for 30cm back, max angle is 39.77^0

DAQ Assistant

NI USB-9162

4-Channel, ±5 V, 24-Bit IEPE Analog Input Module

Number of channels .... 4 analog input channels
ADC resolution .... 24 bits
Type of ADC...Delta-sigma (with analog pre-filtering)
Master timebase (internal)
Frequency.. 12.8 MHz
Accuracy .... ±100 ppm max
Input coupling ....AC
AC cutoff frequency
–3 dB... 0.5 Hz typ
–0.1 dB .... 4.2 Hz max
AC voltage full-scale range
Typical..±5.4 Vpeak
Minimum..±5 Vpeak
Maximum ....±5.8 Vpeak
Common-mode voltage
(AI– to earth ground) ....±2 V
IEPE excitation current
Minimum ....2.0 mA
Typical..2.2 mA
IEPE compliance voltage........................19 V max
Accuracy (0 to 60 °C)
Error Accuracy
Calibrated max ±0.3 dB
Calibrated typ ±0.1 dB
Uncalibrated max ±0.6 d**s**
Accuracy drift
Typical .... 0.001 dB/°C
Maximum....................................... 0.0045 dB/°C
Channel-to-channel matching
Gain

Maximum................................ 0.27 dB
Typical .... 0.07 dB

String Potentiometer

GENERAL
Full Stroke Ranges. . . . . .0-3 and 0-5 inches, min.
Output Signal. . . . . voltage divider (potentiometer)
Accuracy. . . . .±0.4 % full stroke
Repeatability. . . . . ±0.02% full stroke
Resolution . . . . essentially infinite
Potentiometer Cycle Life .. . . . 50 million cycles*
Measuring Cable. . . . . .0.024-in. dia. nylon-coated stainless steel
Enclosure Material. . . . . .anodized aluminum
Sensor . . . . conductive plastic potentiometer
Weight (maximum) . . . . 3-inch: 0.10 lbs., 5-inch: 0.26 lbs.

ELECTRICAL
Input Resistance . . . . .5K ohms (±10%)
Power Rating, Watts. . . . . .1.0 at 40º C (derated to 0 @ 110ºC)Recommended Maximum
Input Voltage. . . . . 30V (AC or DC)
Temperature coefficient of voltage dividing ratio. . . . . < 2 ppm/°C
Temperature coefficient of resistance-50...+75°C. . . . . ±200 ppm/°C
+75...+100°C. . . . . ±300 ppm/°C
Output Signal Change Over Measurement Range . . . . .94% ±4% of input voltage

ENVIRONMENTAL
Enclosure Design. . . . . .NEMA 12, IP55
Operating Temperature. . . . .-67º to 212ºF (-55º to 100ºC)

13.3 User Guide

The first step involves the setting up of the pot at the correct height. In order to do this, the subject needs to be asked his/her height. Based on the height of the subject and the marking on the device, the pot should be adjusted to the right height.

The next step involves the subject wearing the belt. The PI will assist the subject in wearing the belt as tight as possible on to the hip. The PI will also rotate such that string of the pot is close to the skin and is located at the T12.

The subject should now be assisted to wear the chest belt or the straps in order to attach the string to the shirt/top.

The string should now be attached to the shirt/top using a Velcro strip.

An additional waist belt can be worn by the subject to support the device.

The width of the back of the subject is measured using a tape in cms.

The treadmill can now be started at low speeds first and then high speeds. Once the investigator gains reasonable confidence that the device is working fine, the readings can be taken.

The readings should be taken in the middle as the subject might need sometime to get accustomed to the treadmill.

Using Labview, readings at different speeds can be recorded and stored. The Labview will convert the voltage change in to a certain angle change which is of our interest.

The stored readings can be put into the Matlab program provided to obtain average max angle, average max velocity and average max acceleration. This Matlab program will also give out a graphical representation of the angle, velocity and acceleration change with time.

13.4 Calibration

Using simple calibration techniques, we pulled the string out of the potentiometer and took the readings for voltage change for different lengths. These Values are shown below which were later plotted on a graph.

Length (cm)	Angle (in radians)	Angle (in degrees)
1	0.11	6.53
2	0.69	39.71
3	1.27	73.00

The derived equation from these values was:

y = (x*4.35-2.644)*28.7*width of the back

y is the angle of rotation in degrees

x is the length of the pot which is extended

The following linearity was obtained when plotted on a graph.

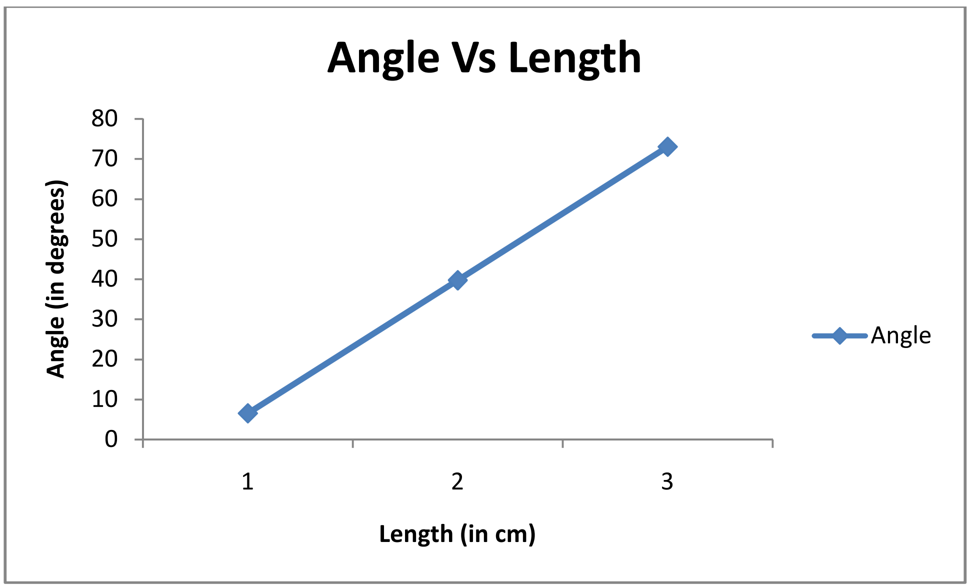

Figure 32: Linearity of the Pot Voltage change with Length